Strain and Strain Rate Imaging
How, Why and When?

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Cleveland Clinic Foundation

Disclosures: No conflicts of interest

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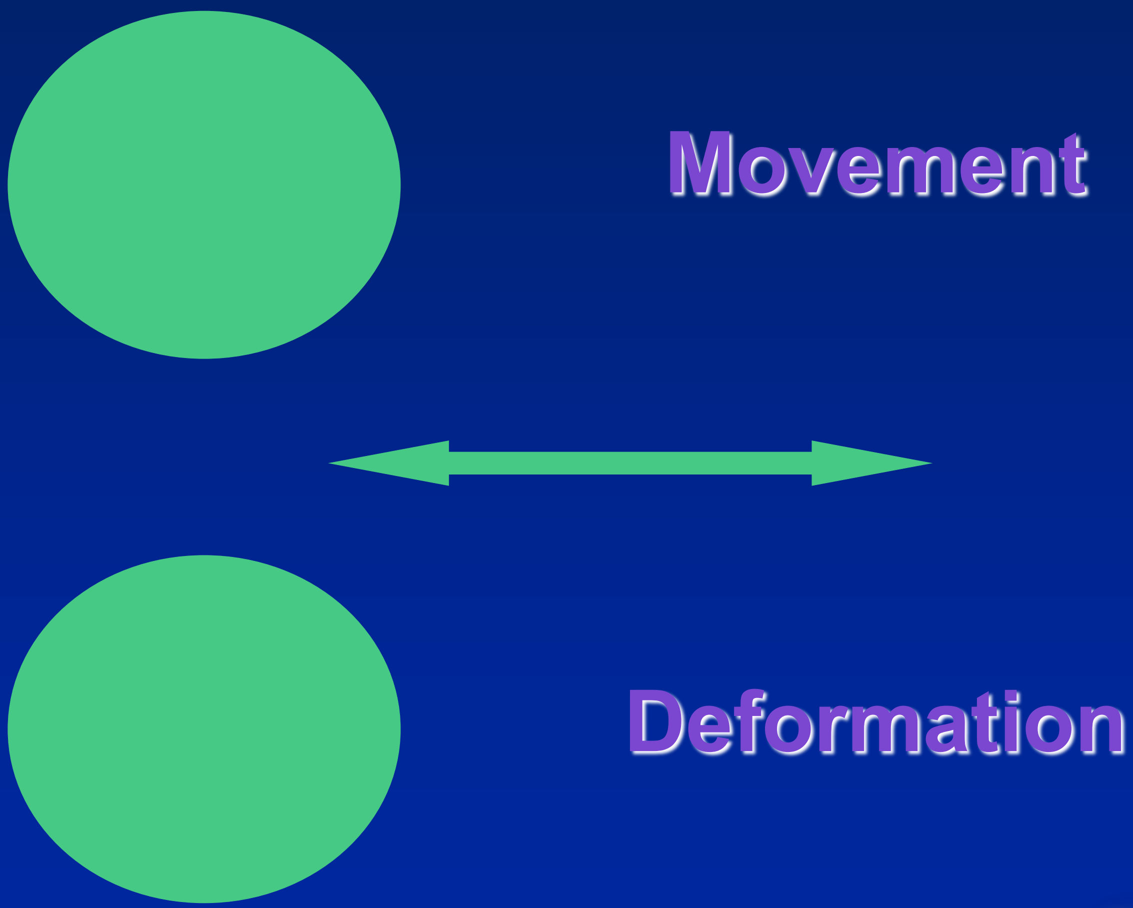
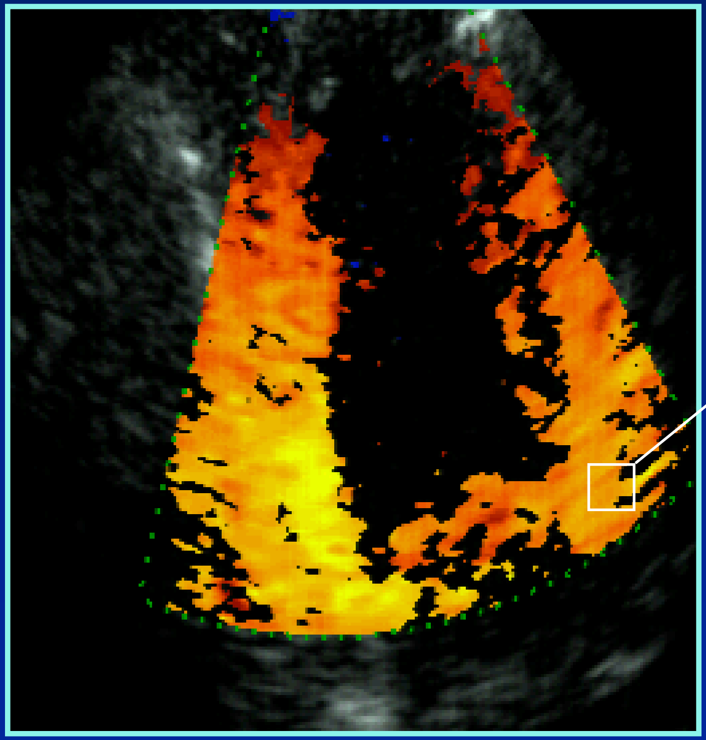
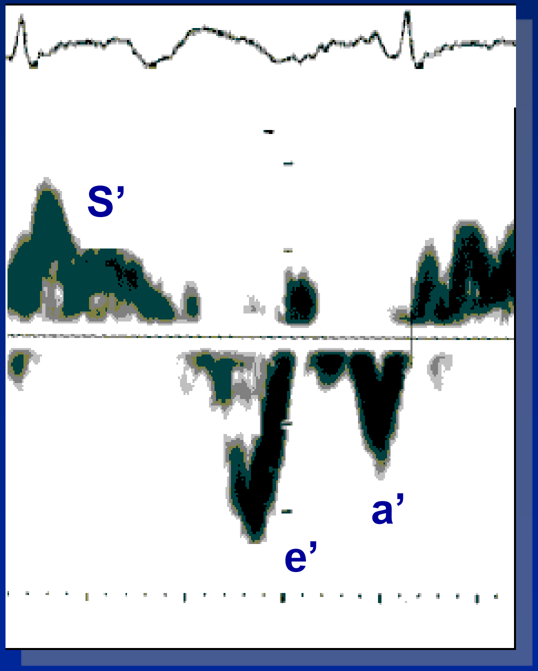
Movement vs Deformation



Doppler Myocardial Velocities



Color DTI



Pulsed DTI

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Tissue Velocity Imaging cannot Discriminate between Actively Contracting Muscle and Muscle that is moving because of Tethering

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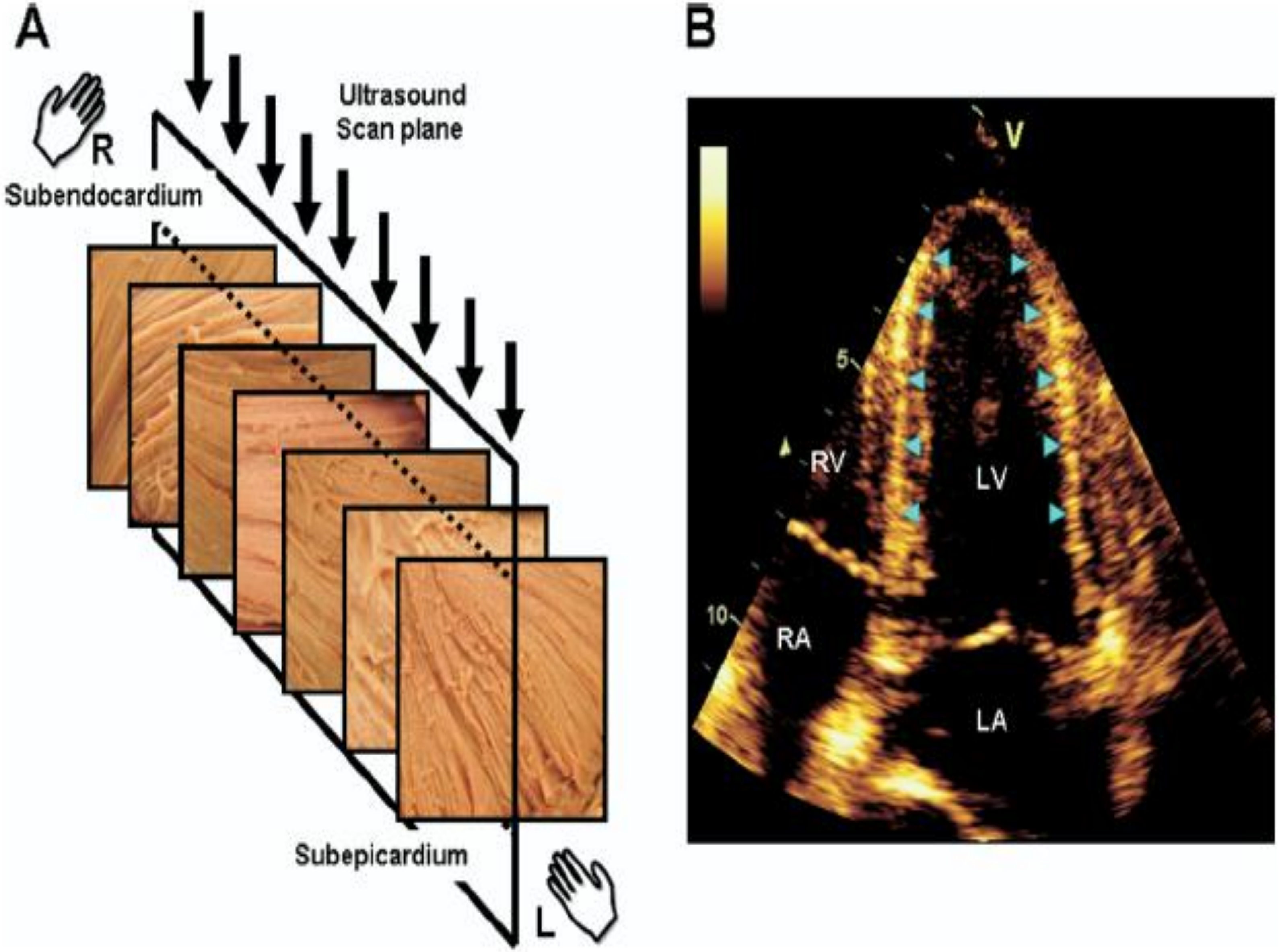

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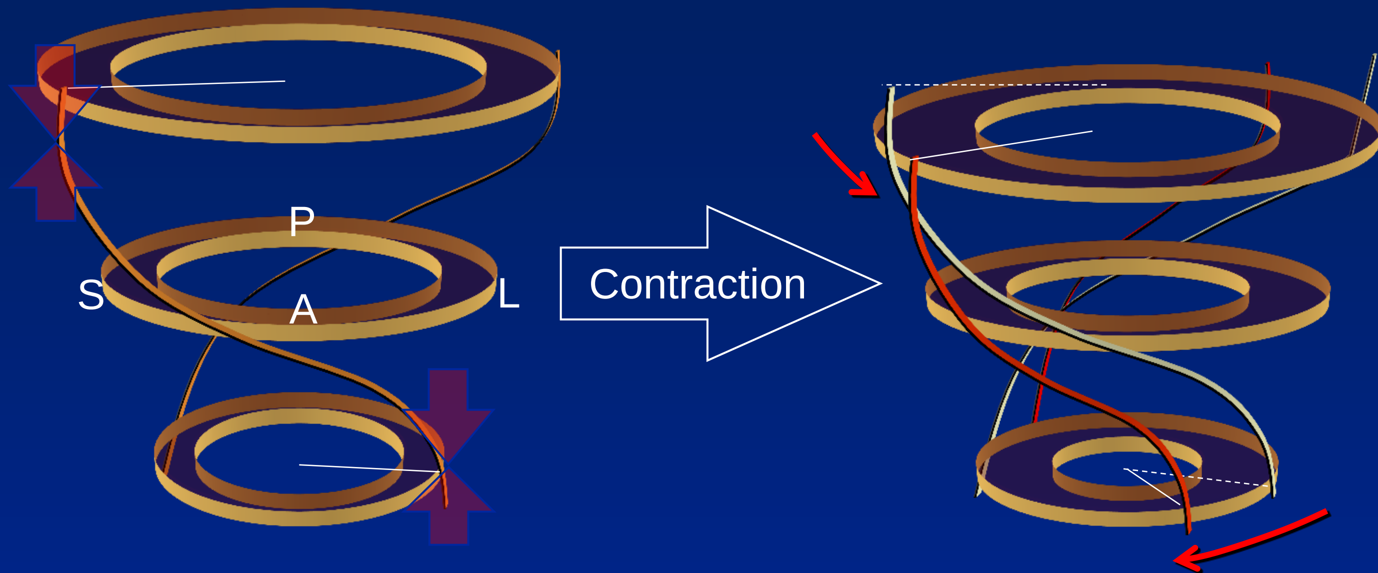
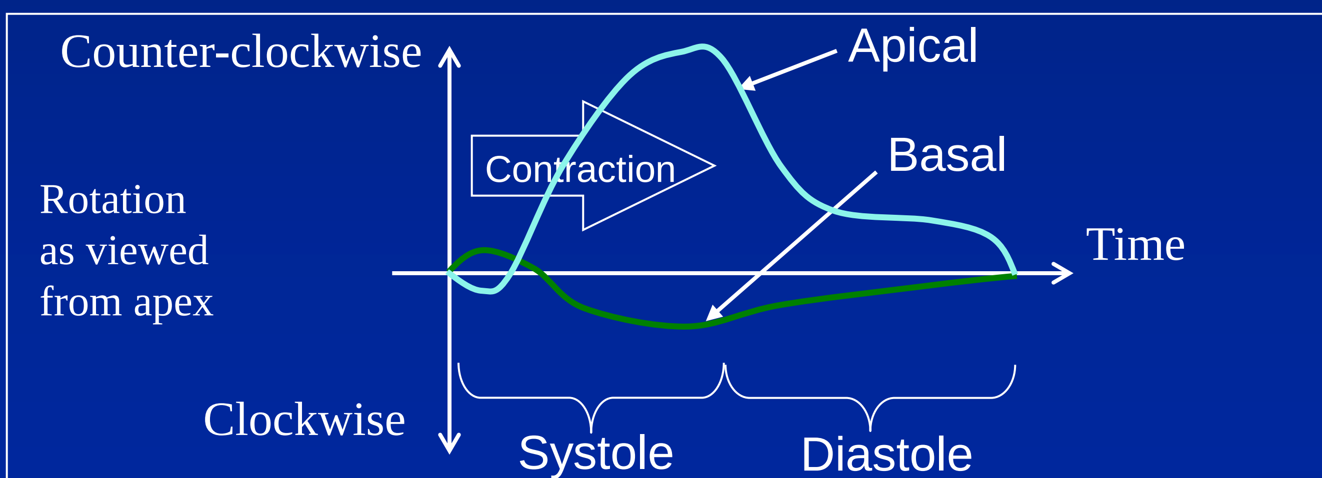
Normal Strain and Torsion





Notomi et al. Circulation 2005; 111: 1141-7

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Strain = deformation

- *Strain is defined as the deformation of an object, normalized to its original shape.*
- ***Strain Rate (SR) should be understood as the rate of myocardial deformation over a period of time.***
- $Strain\ Rate\ (SR) = \frac{Strain}{time}$

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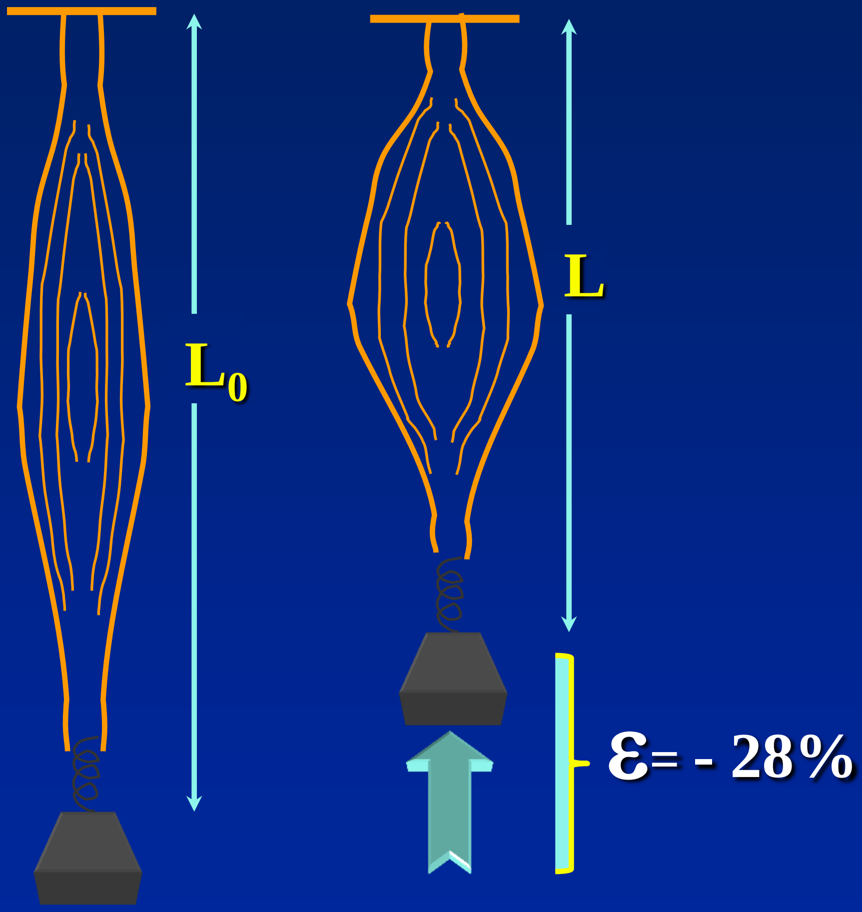
Strain Calculation

- $Strain\ (\varepsilon) = \dfrac{L - L_0}{L_0}$
- $Strain\ (\varepsilon) = \dfrac{7 - 9}{9}$



Mirsky and Parmley. Circ Res, 1973

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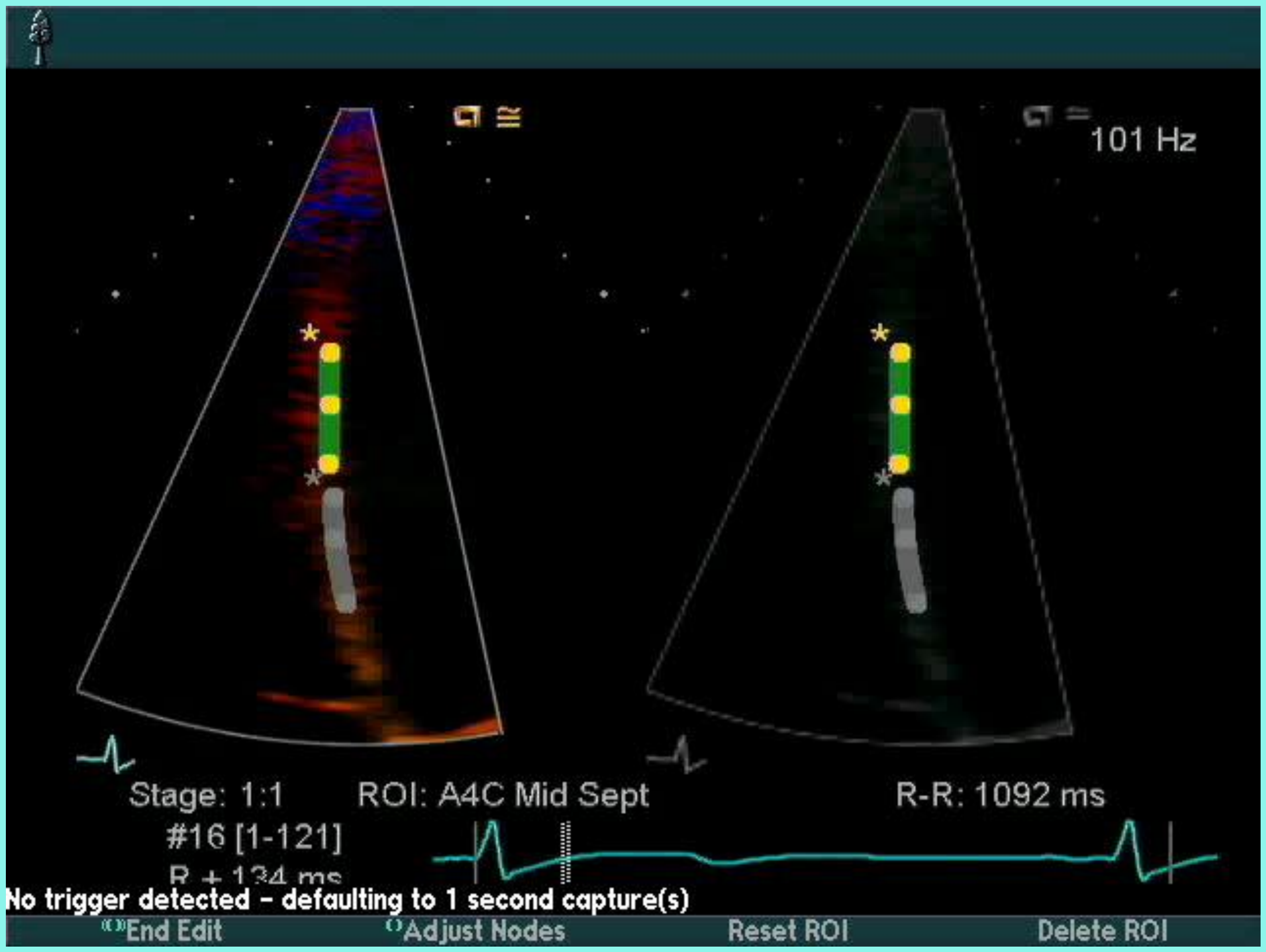
Strain Calculation from Tissue Velocities



Strain tracking

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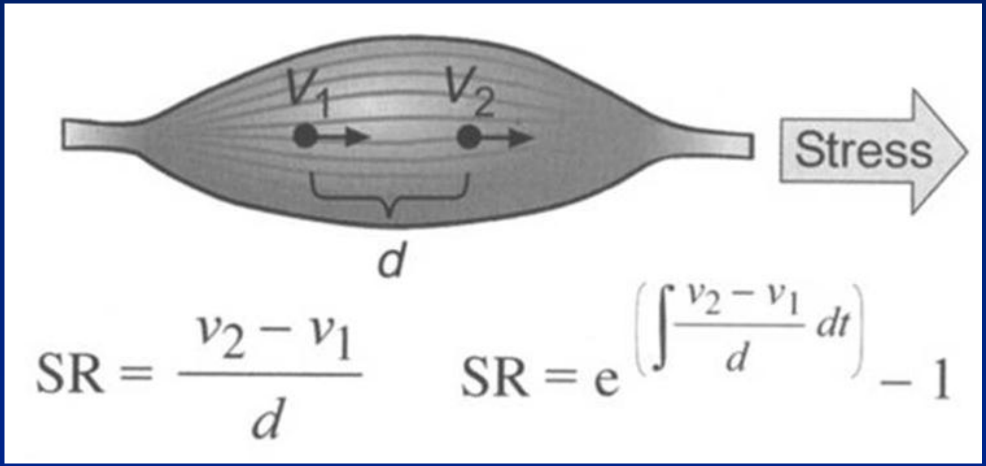
Strain Rate Calculation



- Distance is calculated by velocity, ie: Distance=Velocity x Time
- If $V_1 > V_2$, SR is **negative** and there is **shortening**
- If $V_2 > V_1$, SR is **positive**, indicating **lengthening**
- If $V_1 = V_2$, SR is **zero**, no shortening nor lengthening.

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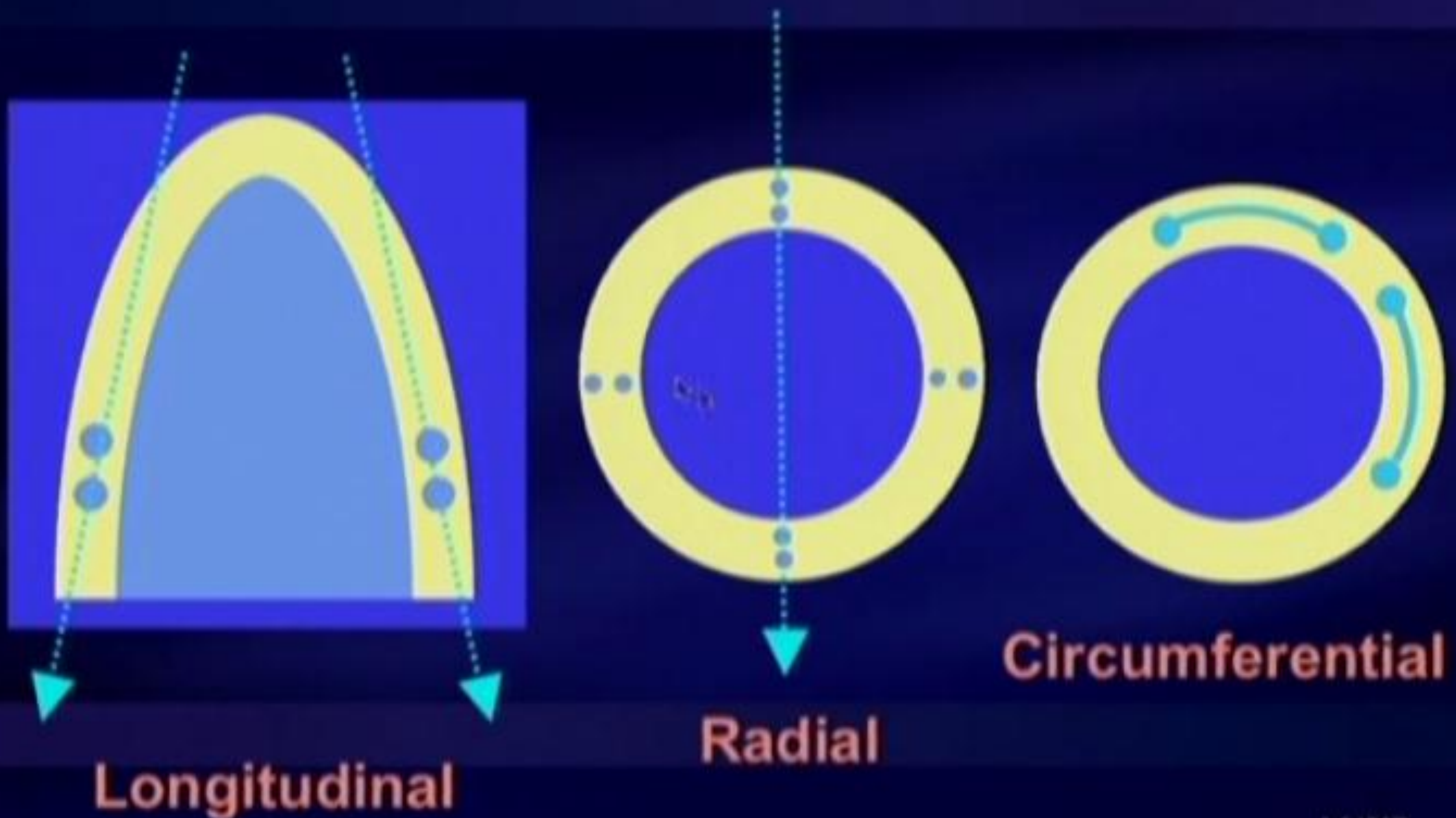
Directions of Cardiac Strain



Caveats of TD derived Strain

- *Doppler angle-dependent*
- *The comparison of adjacent velocities is exquisitely sensitive to signal noise ratio.*
- *High frame rates needed. (lower spatial resolution).*

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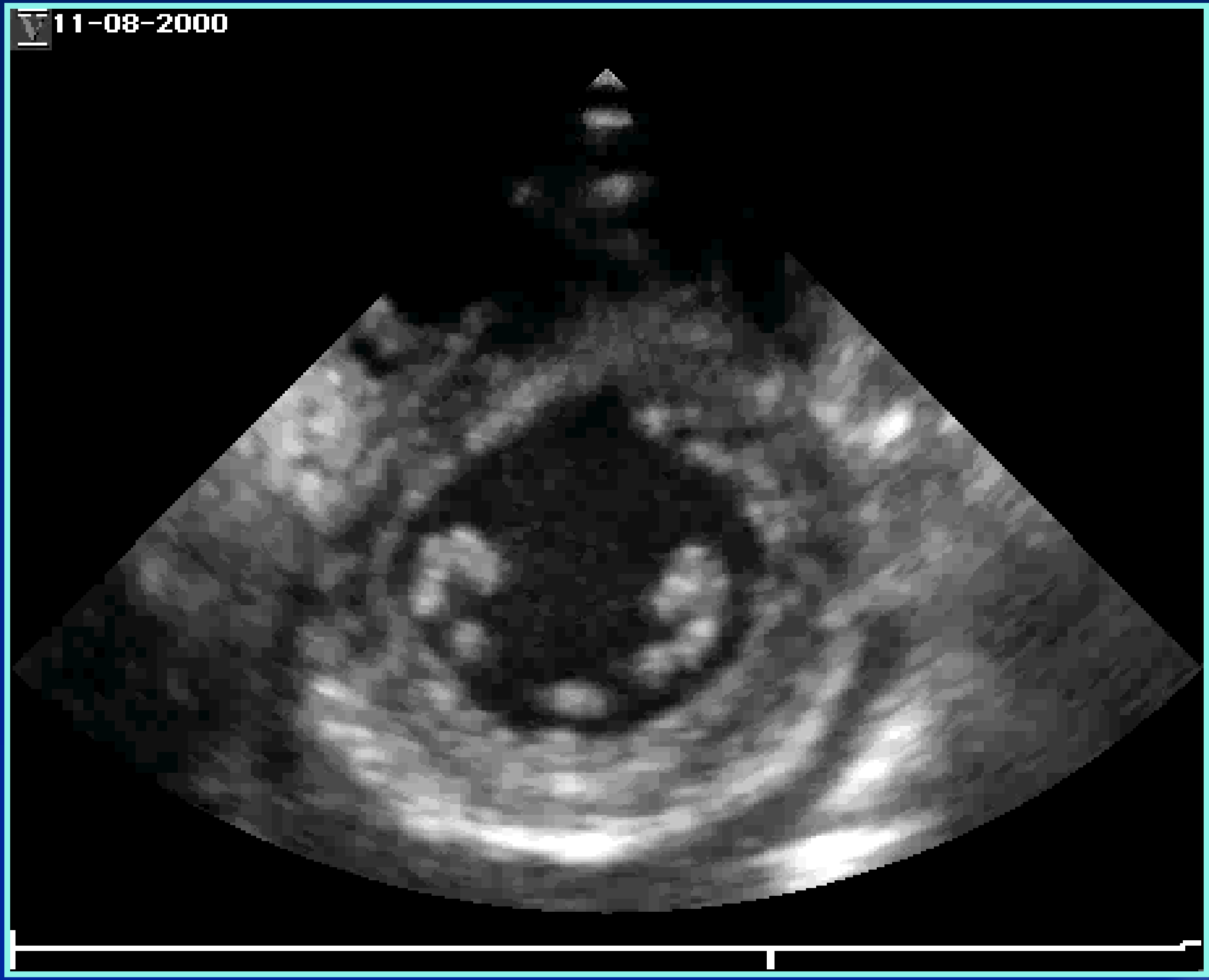
Is it possible to derive strain directly from the B-mode image??



Not a New Idea, Just Better Implementation

COMPUTERS IN CARDIOLOGY 1988

LOCAL MYOCARDIAL DEFORMATION COMPUTED FROM SPECKLE MOTION

Jean Meunier, Michel Bertrand, Guy E. Mailloux and Robert Petitclerc

Ecole Polytechnique, C.P. 6079, Station "A"
and Institut de Cardiologie, 5000 Belanger E.,
Montreal, H1T 1C8, CANADA

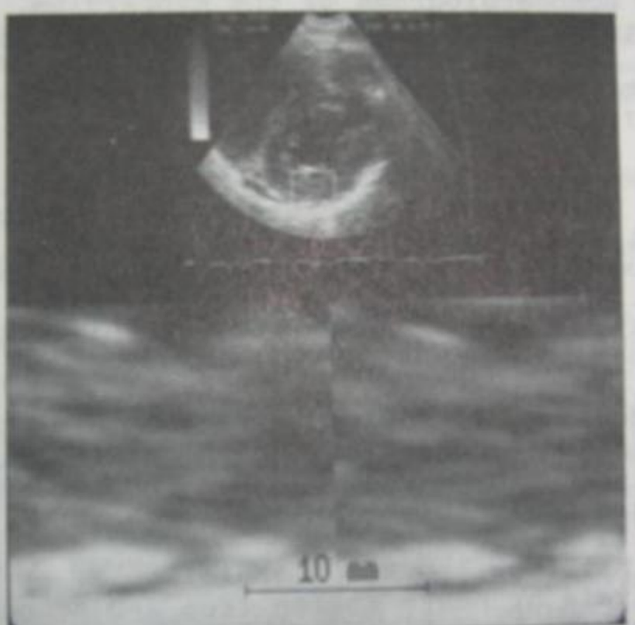


Fig. 2 A typical echocardiographic image (short axis view) and two successive frame ROI after lowpass filtering near end-diastole.

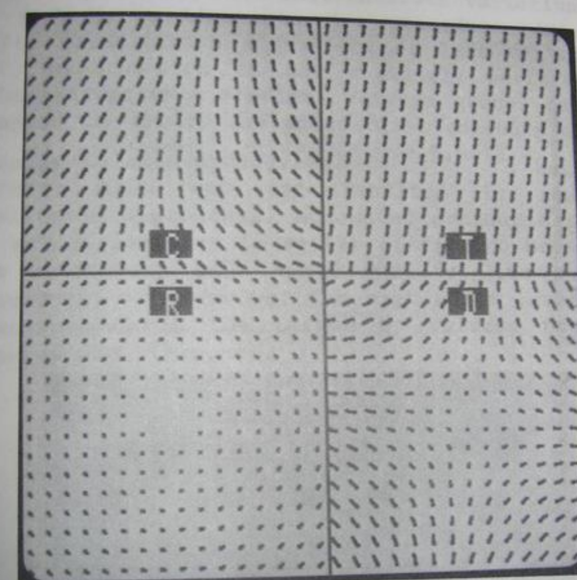
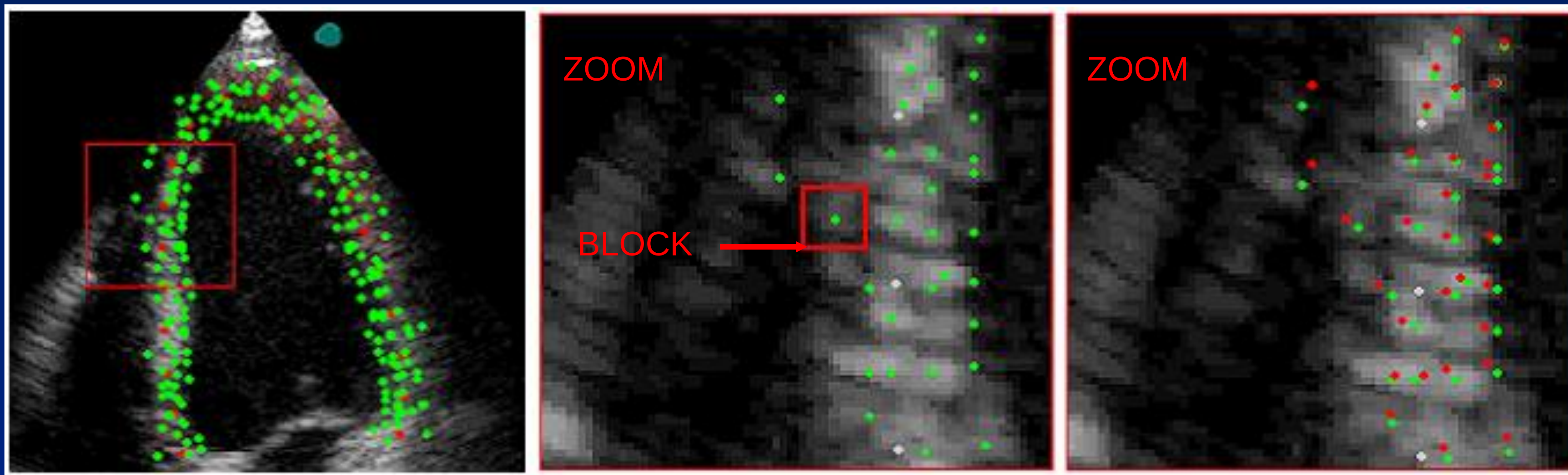
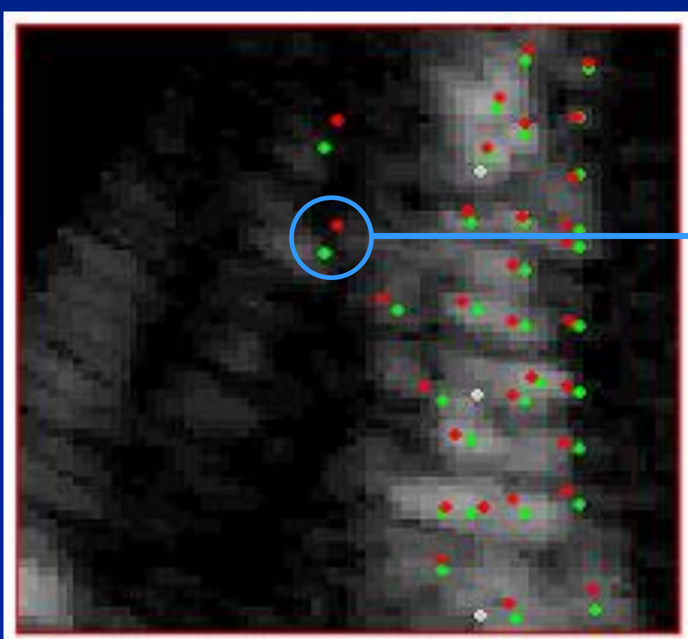
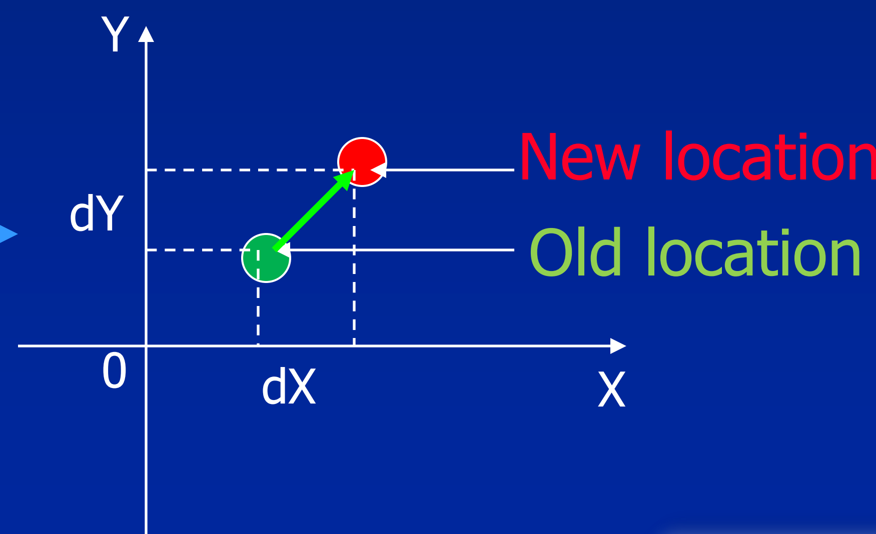


Fig. 3 Velocity (motion) vector fields computed from the two ROI in fig. 2 near end-diatole. The composite (C), translational (T), rotational (R) and deformation (D) fields are represented. The coordinate origin is the ROI center.

Derivation of 2D Strain by Echo







Leitman M et al. JASE 2004; 17:1021-29

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How to Obtain and Analyze 2D Strain in Practice

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Image Acquisition
Longitudinal Strain

- Apical views: 4, 2, 3 chamber on axis, non foreshortened
- Narrow 2D sector width to include entire LV and myocardium, and base of LA
- FPS should be between 40 – 90 or at least 40% of HR.
- Initiate breathing techniques
- Acquire 3 cardiac cycles

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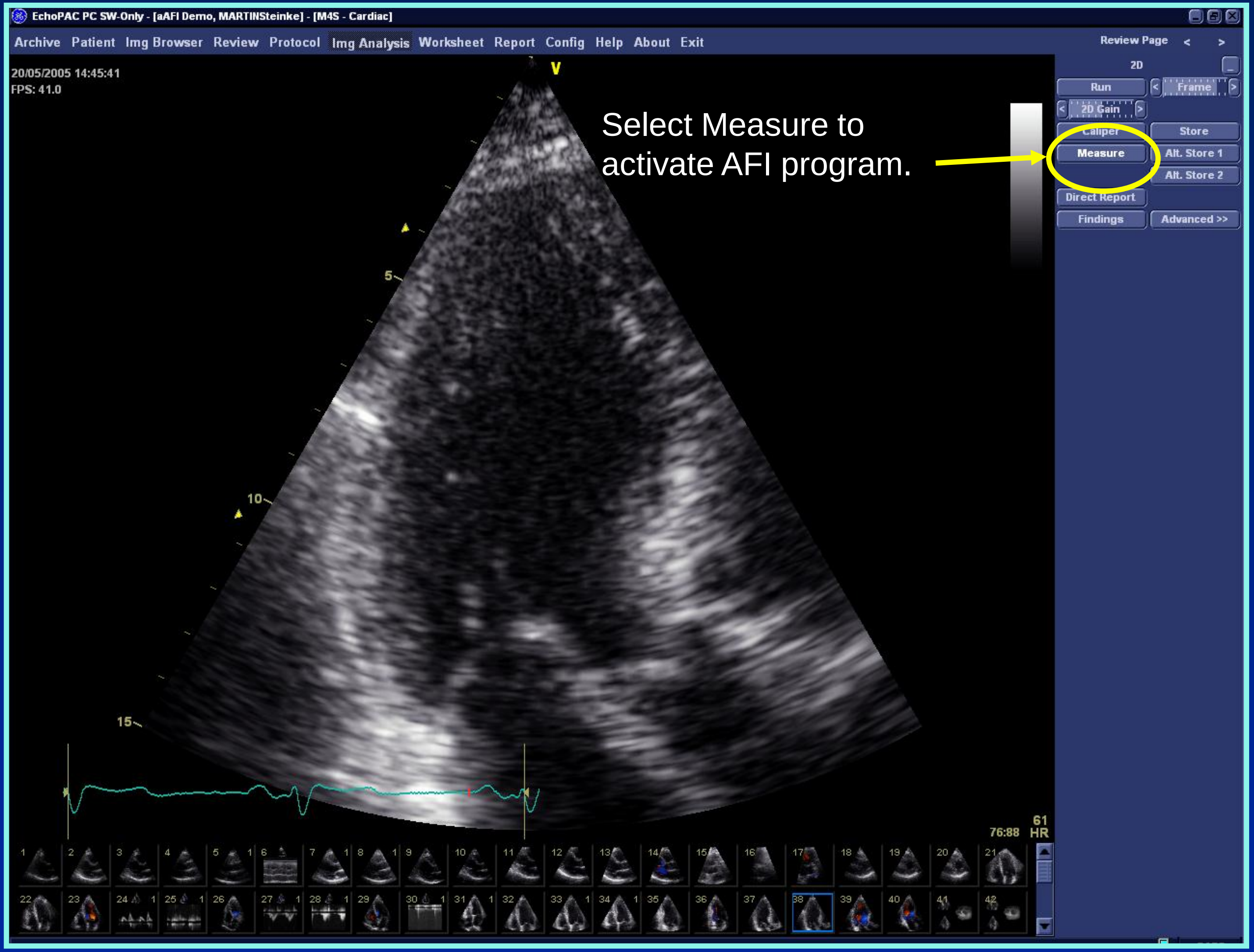
Activate the Program



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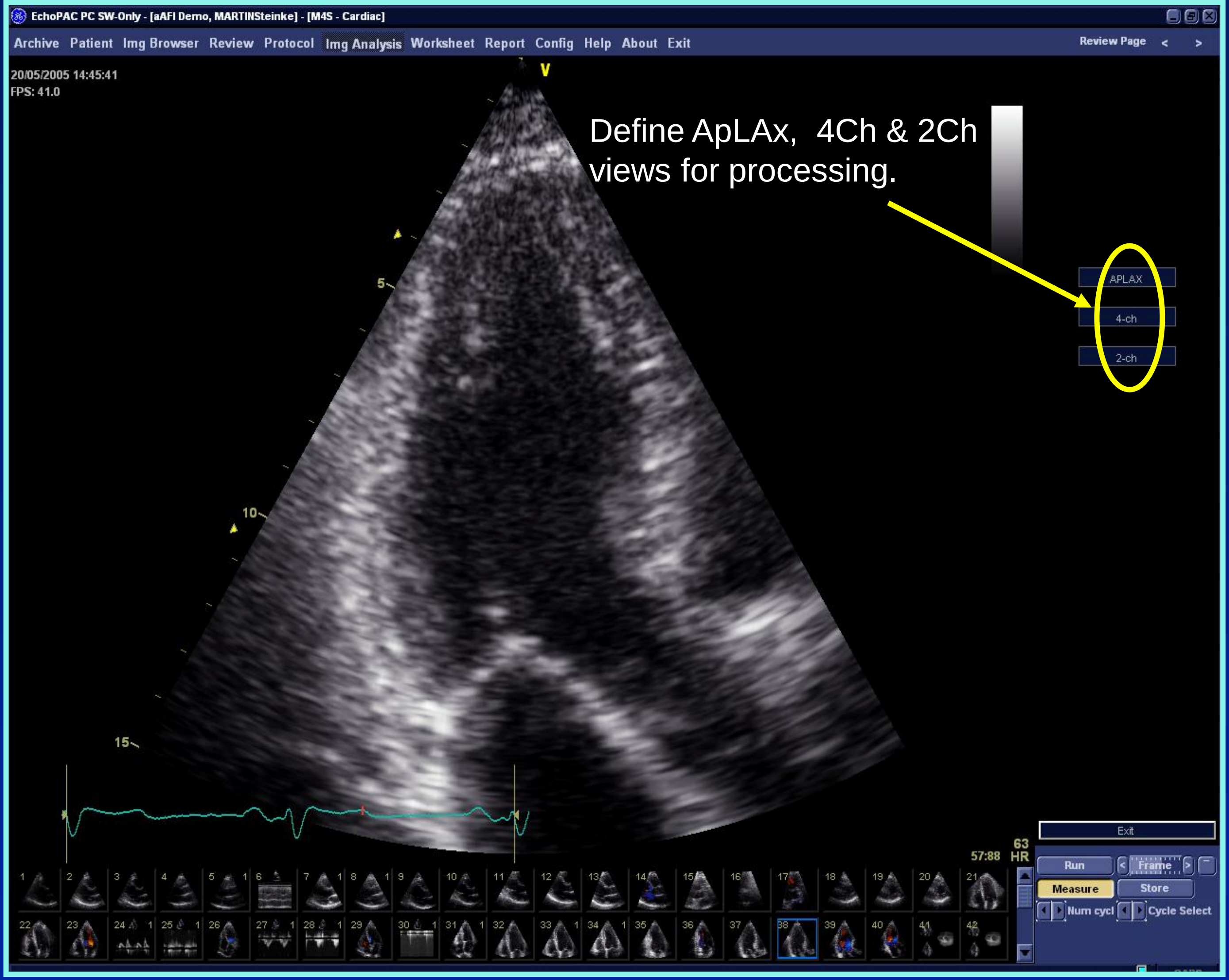
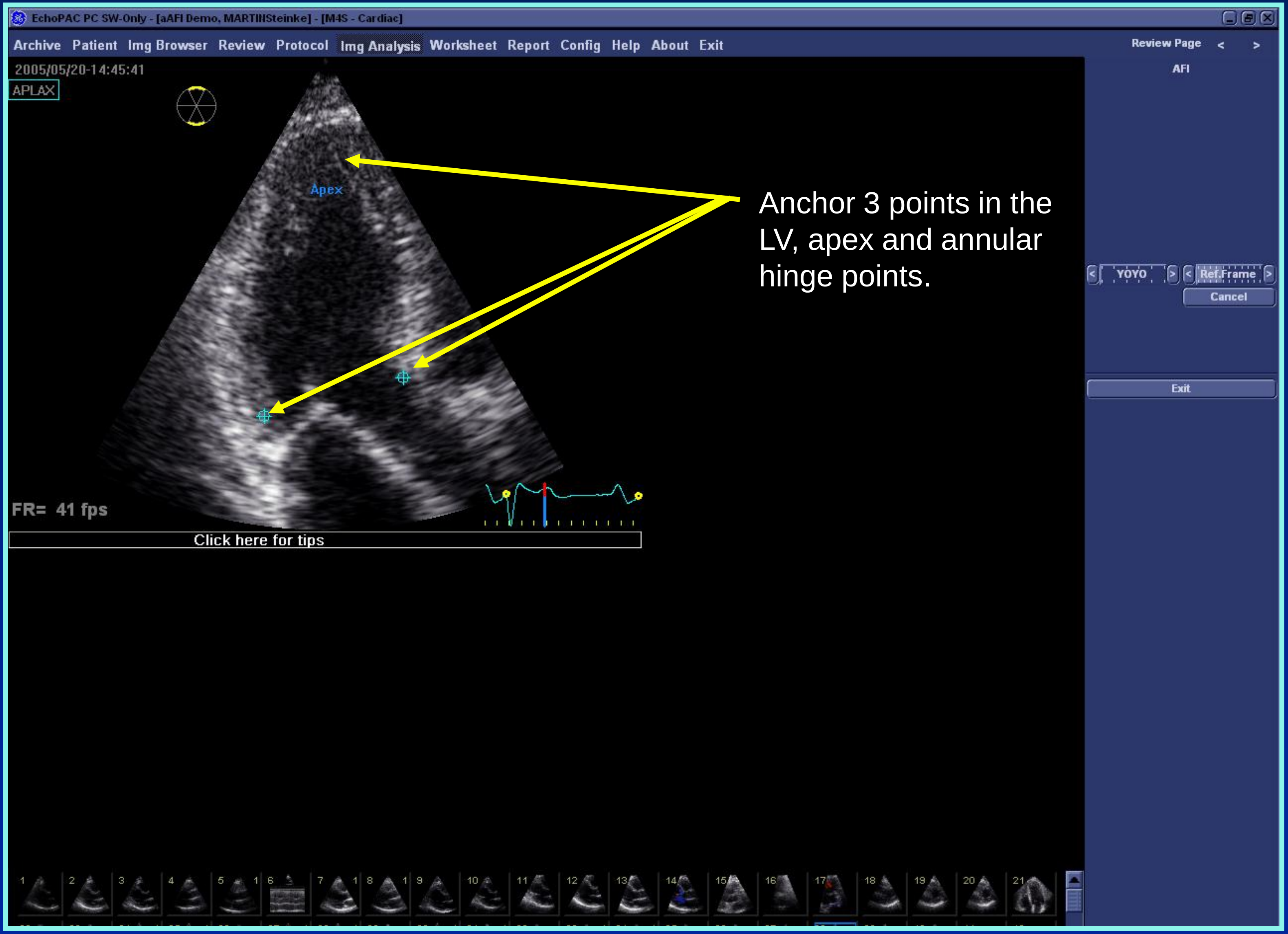
Define the View



Anchor 3 Points



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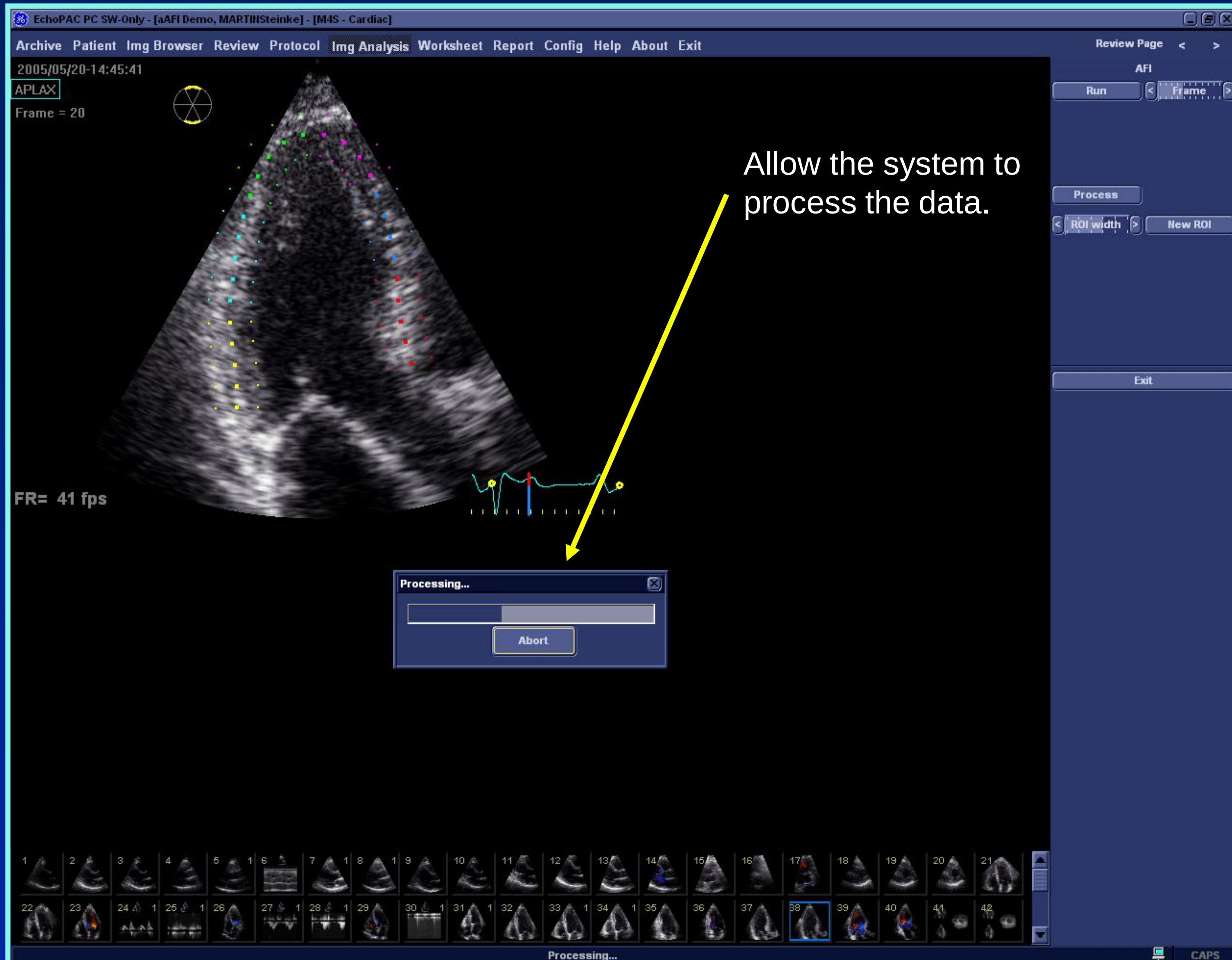
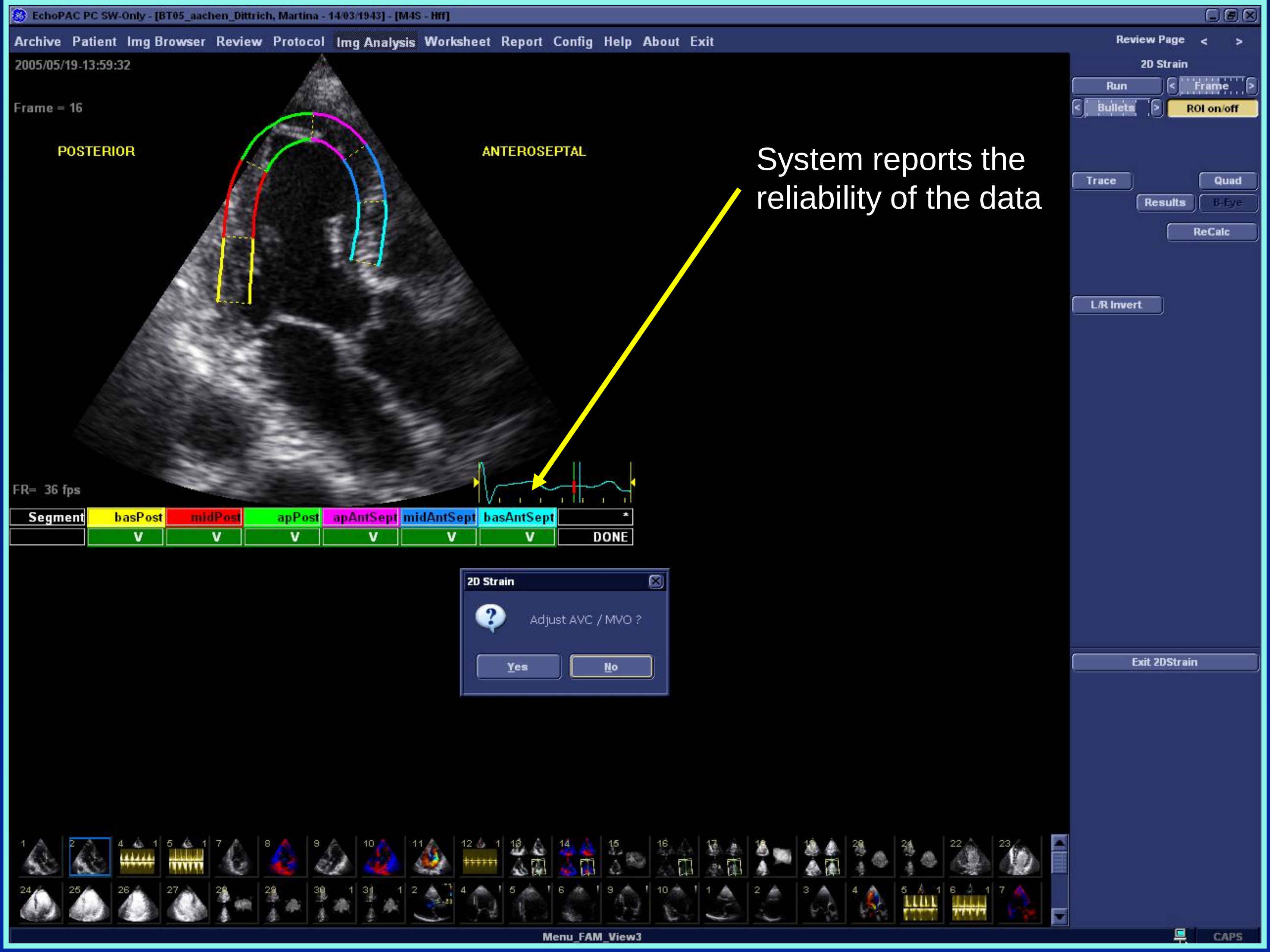
Process the Data



Read the Reliability of the Fit



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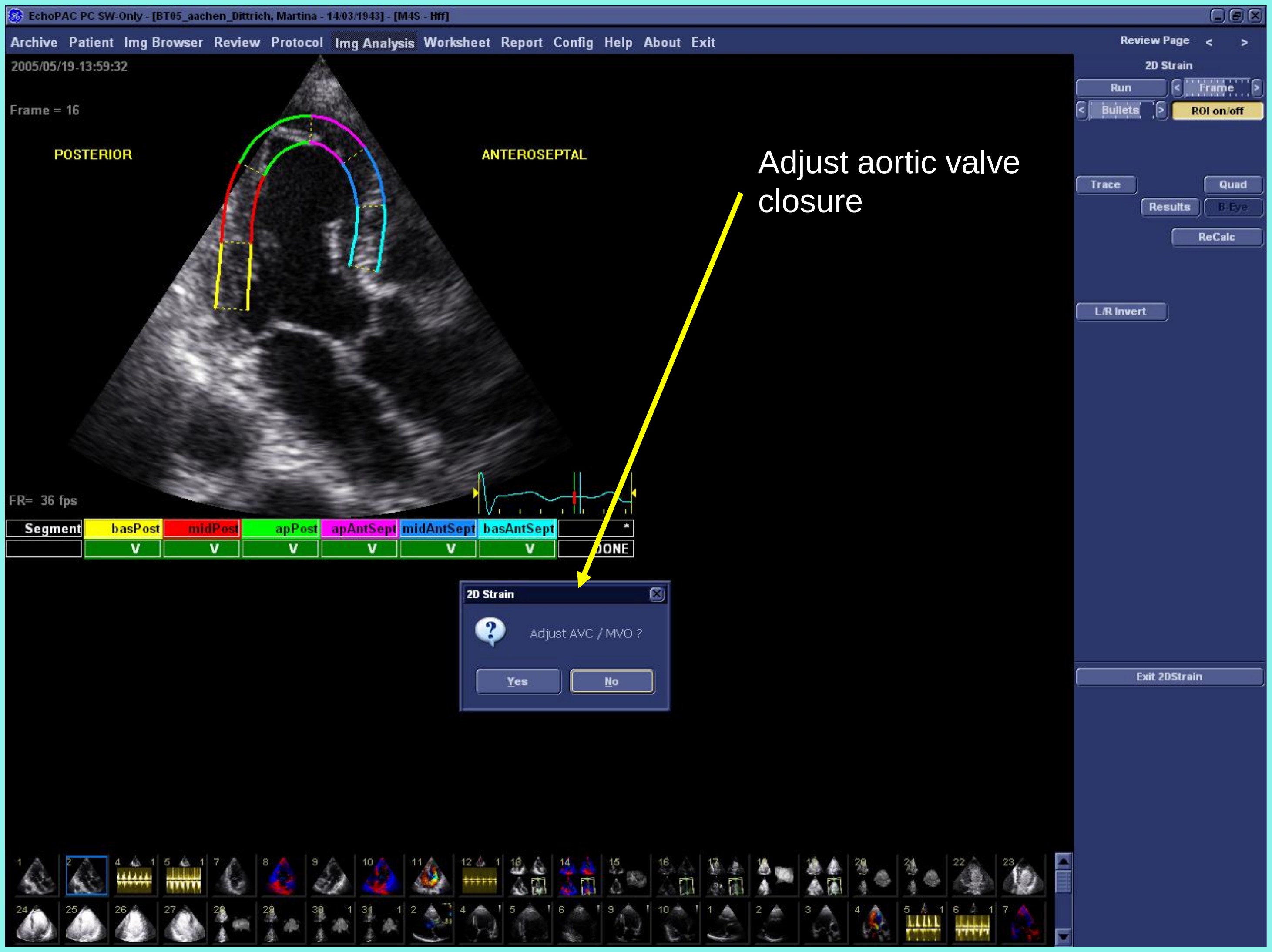
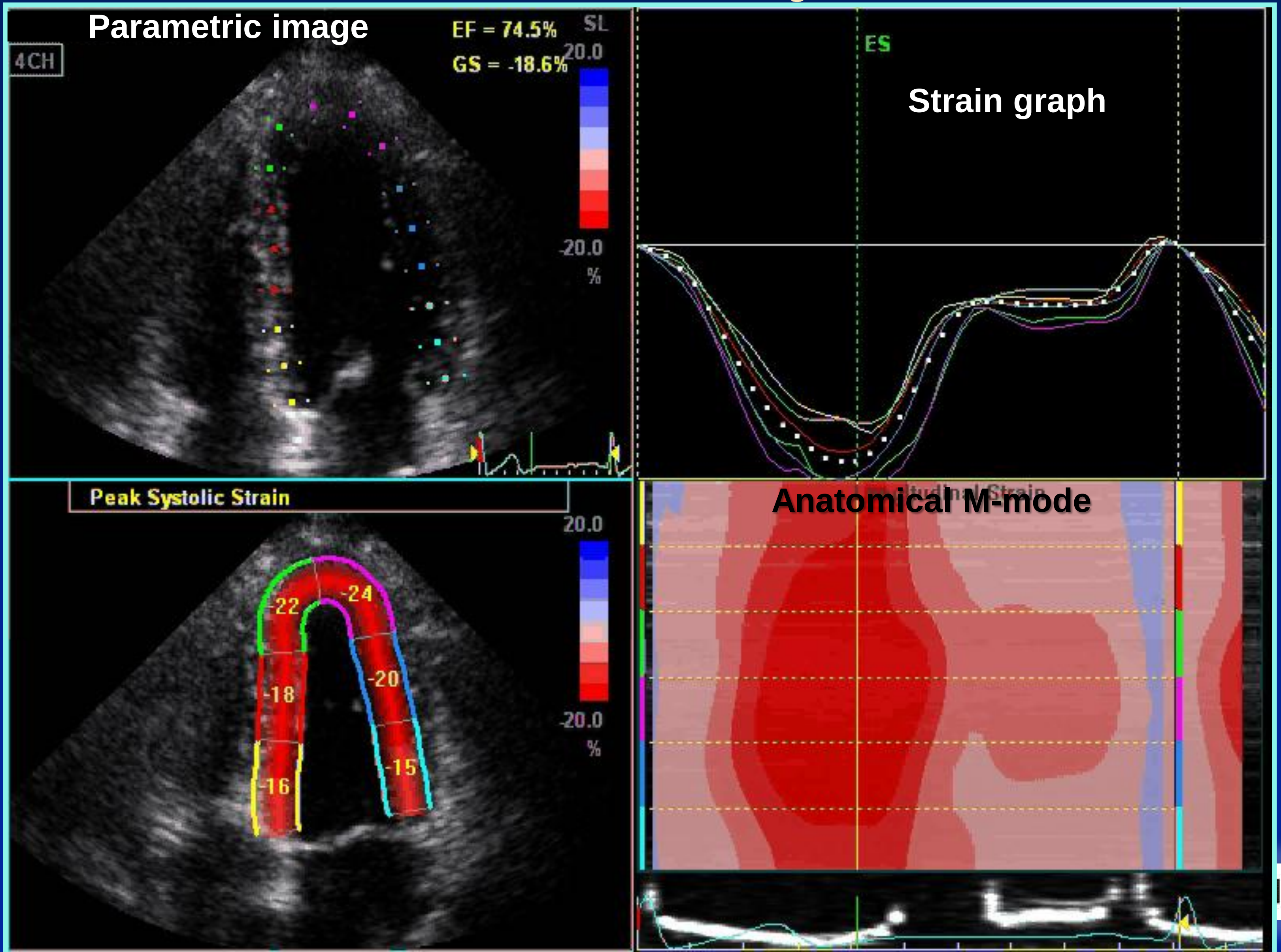
Set AV Closure (ApLAx)



Longitudinal Strain

Normal Subject



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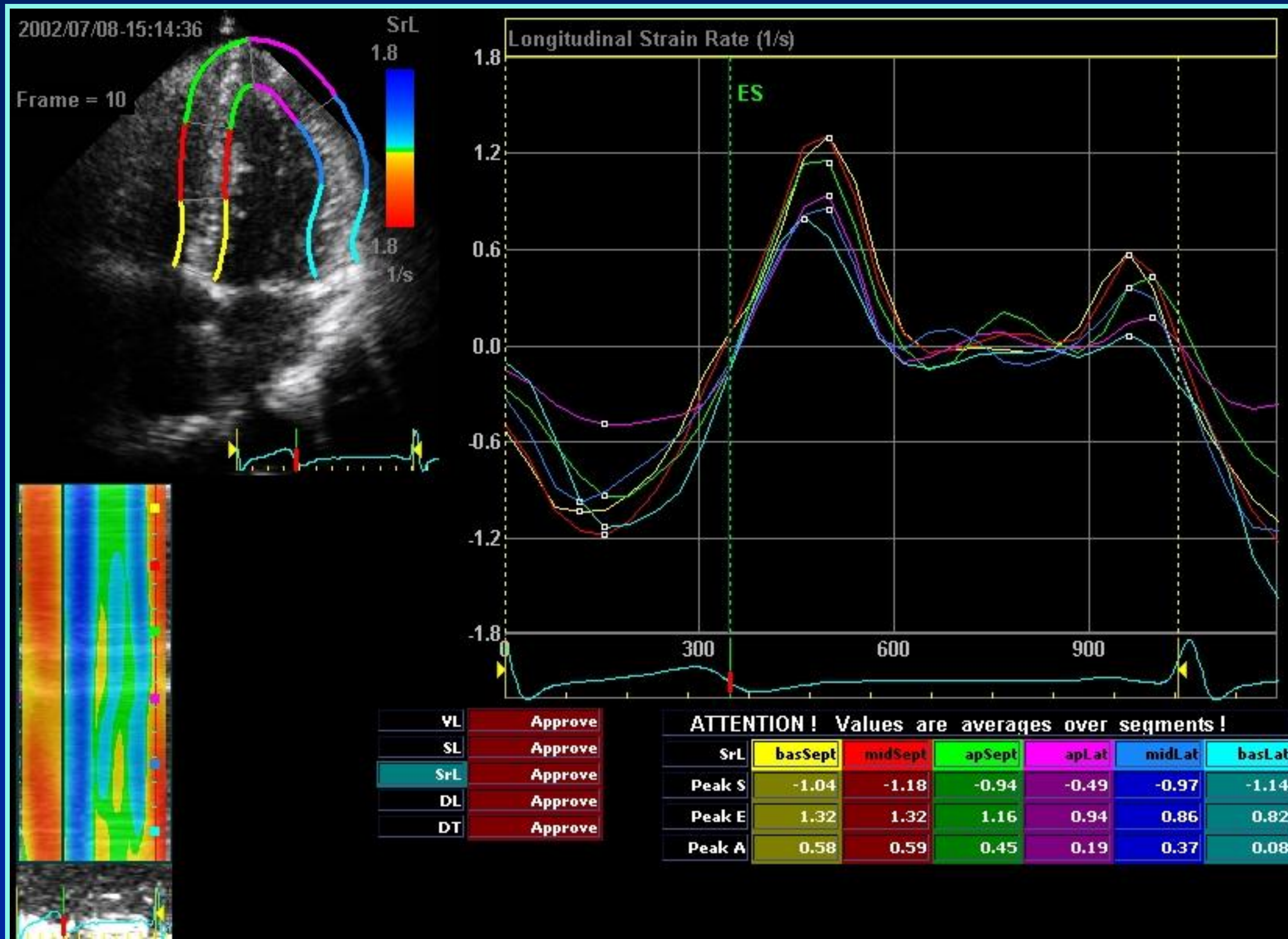
Normal Subject

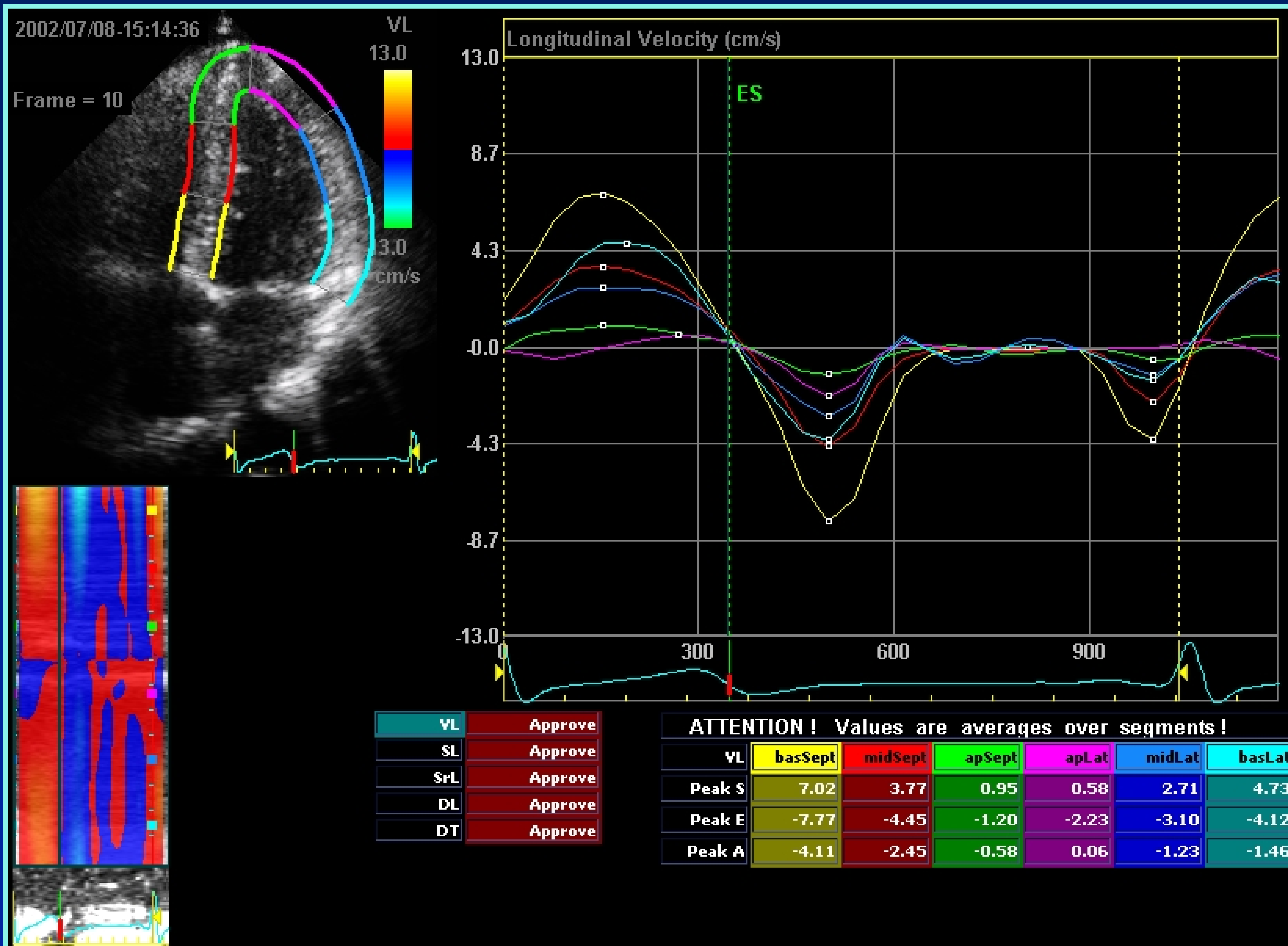
Longitudinal Strain Rate from Apical 4-Chamber



SrL	basSept	midSept	apSept	apLat	midLat	basLat
Peak S	-1.04	-1.18	-0.94	-0.49	-0.97	-1.14
Peak E	1.32	1.32	1.16	0.94	0.86	0.82
Peak A	0.58	0.59	0.45	0.19	0.37	0.08

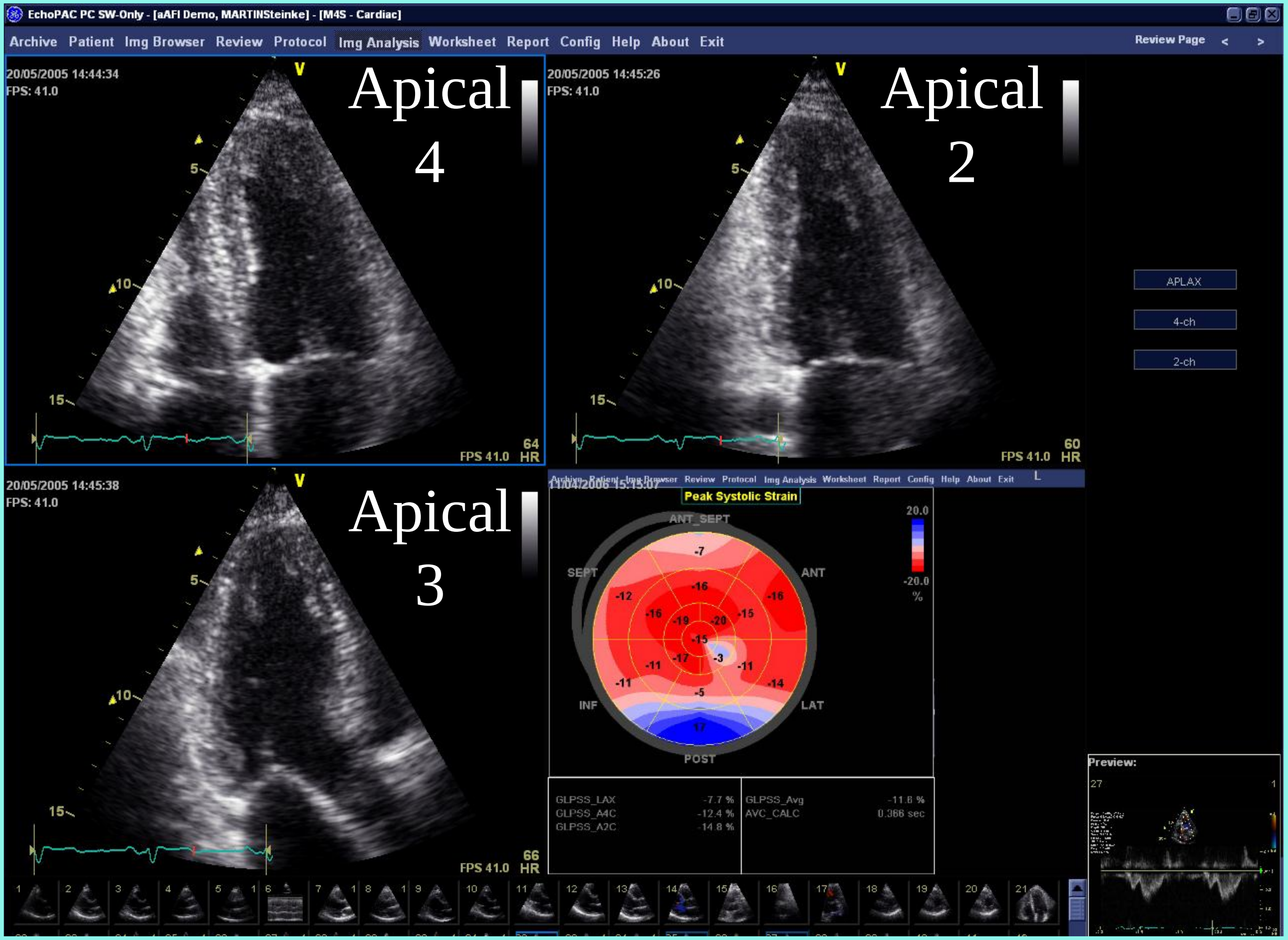
Normal Subject

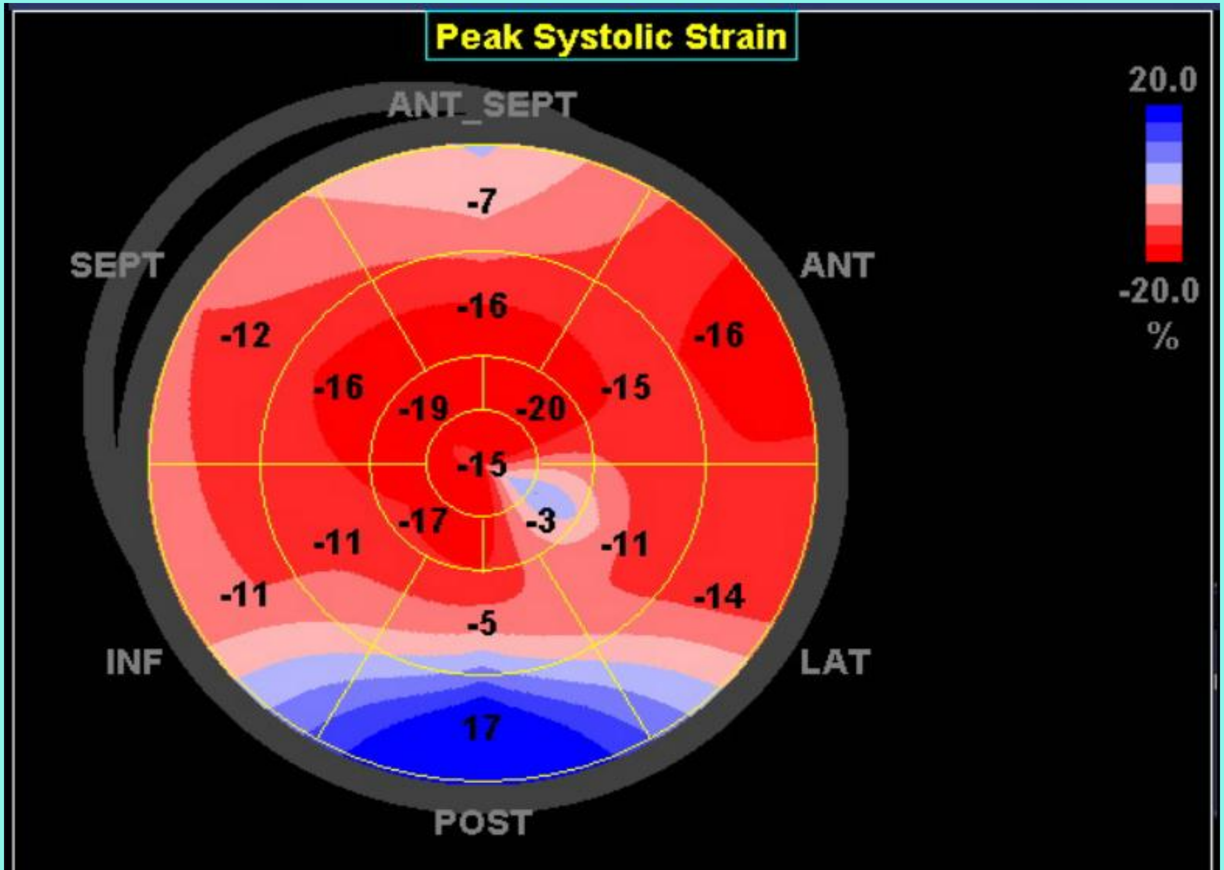
Longitudinal Velocity from Apical 4-Chamber



VL	basSept	midSept	apSept	apLat	midLat	basLat
Peak S	7.02	3.77	0.95	0.58	2.71	4.73
Peak E	-7.77	-4.45	-1.20	-2.23	-3.10	-4.12
Peak A	-4.11	-2.45	-0.58	0.06	-1.23	-1.46

Bull's-eye Plot from 3 Apical Views





GLPSS_LAX	-7.7 %	GLPSS_Avg	-11.6 %
GLPSS_A4C	-12.4 %	AVC_CALC	0.366 sec
GLPSS_A2C	-14.8 %		

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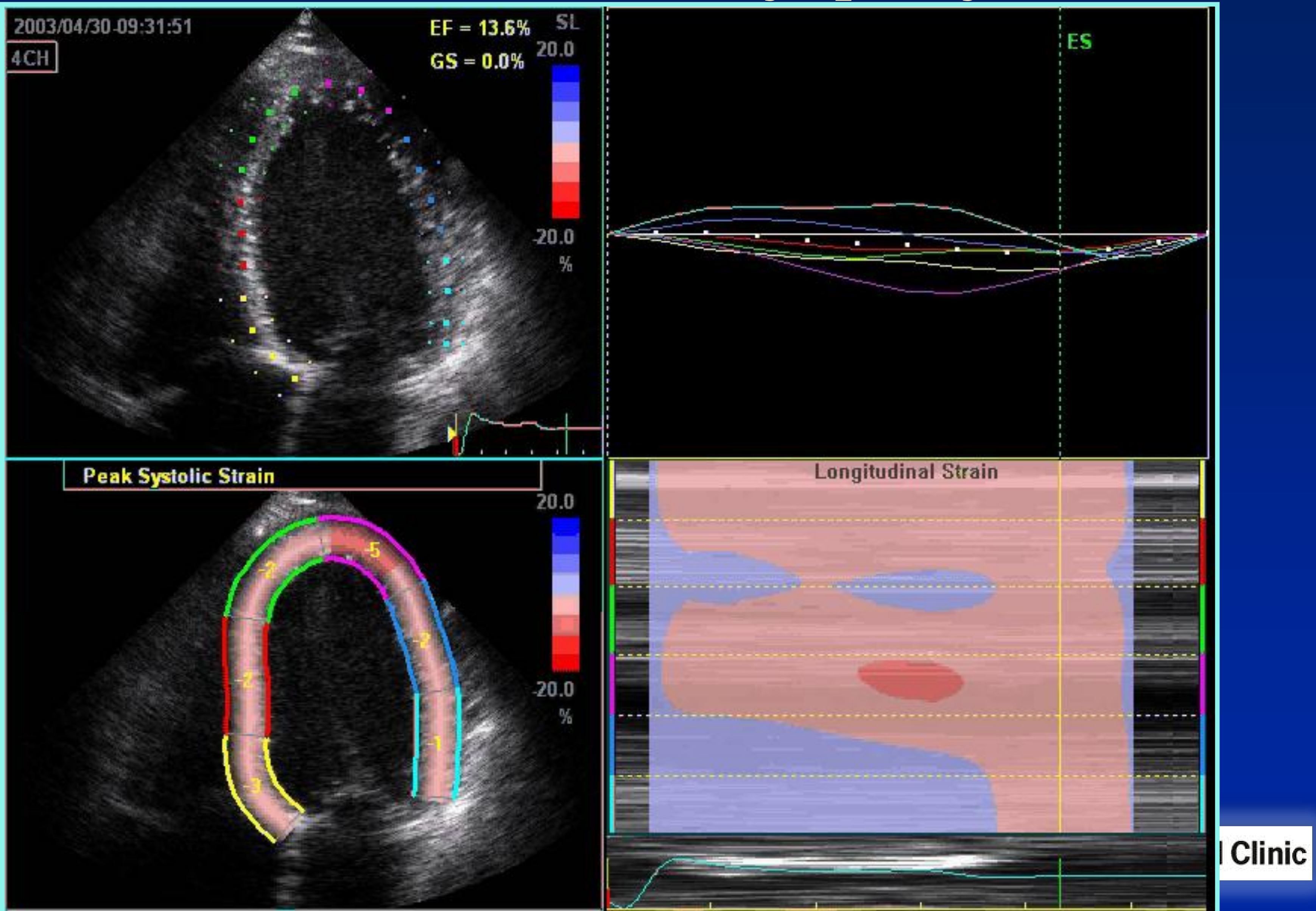
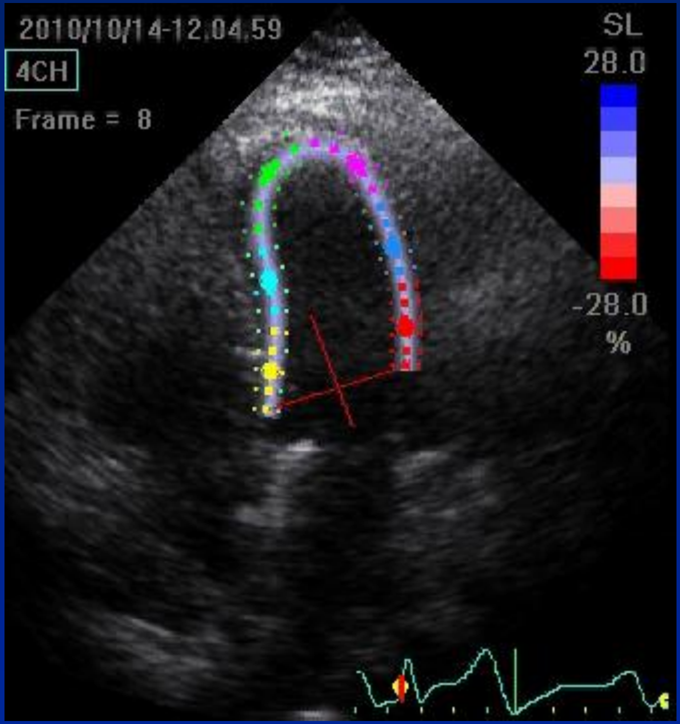
Longitudinal Strain
Dilated Cardiomyopathy



Caveats of Speckle-Tracking derived Strain

- *Not angle-dependent*
- *Highly dependent on image quality and acquisition. (ie: reverberation, attenuation artifacts, etc)*
- *Excessive or limited region-of-interest width*
- *Technical proficiency for measurements.*



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Attempting to define normal ranges for 2D-based speckle-tracking strain

BRIEF REPORT

Myocardial Strain Measurement With 2-Dimensional Speckle-Tracking Echocardiography

Definition of Normal Range

Thomas H. Marwick, MD,* Rodel L. Leano, BS,* Joseph Brown, BS,* Jing-Ping Sun, MD,†
Rainer Hoffmann, MD,‡ Peter Lysyansky, PHD,§ Michael Becker MD,‡
James D. Thomas, MD†

Brisbane, Australia; Cleveland, Ohio; Aachen, Germany; and Haifa, Israel

The interpretation of wall motion is an important component of echocardiography but remains a source of variation between observers. It has been believed that automated quantification of left ventricular (LV) systolic function by measurement of LV systolic strain from speckle-tracking echocardiography might be helpful. This multicenter study of nearly 250 volunteers without evidence of cardiovascular disease showed an average LV peak systolic strain of −18.6 ± 0.1%. Although strain was influenced by weight, blood pressure, and heart rate, these features accounted for only 16% of variance. However, there was significant segmental variation of regional strain to necessitate the use of site-specific normal ranges. (J Am Coll Cardiol Img 2009;2:80–4)

JACC cardiovascular Imaging

Table 2. Comparison of Segmental Values (Mean and SD) for LV Strain (TQ <3), With a Repeated Measures Design

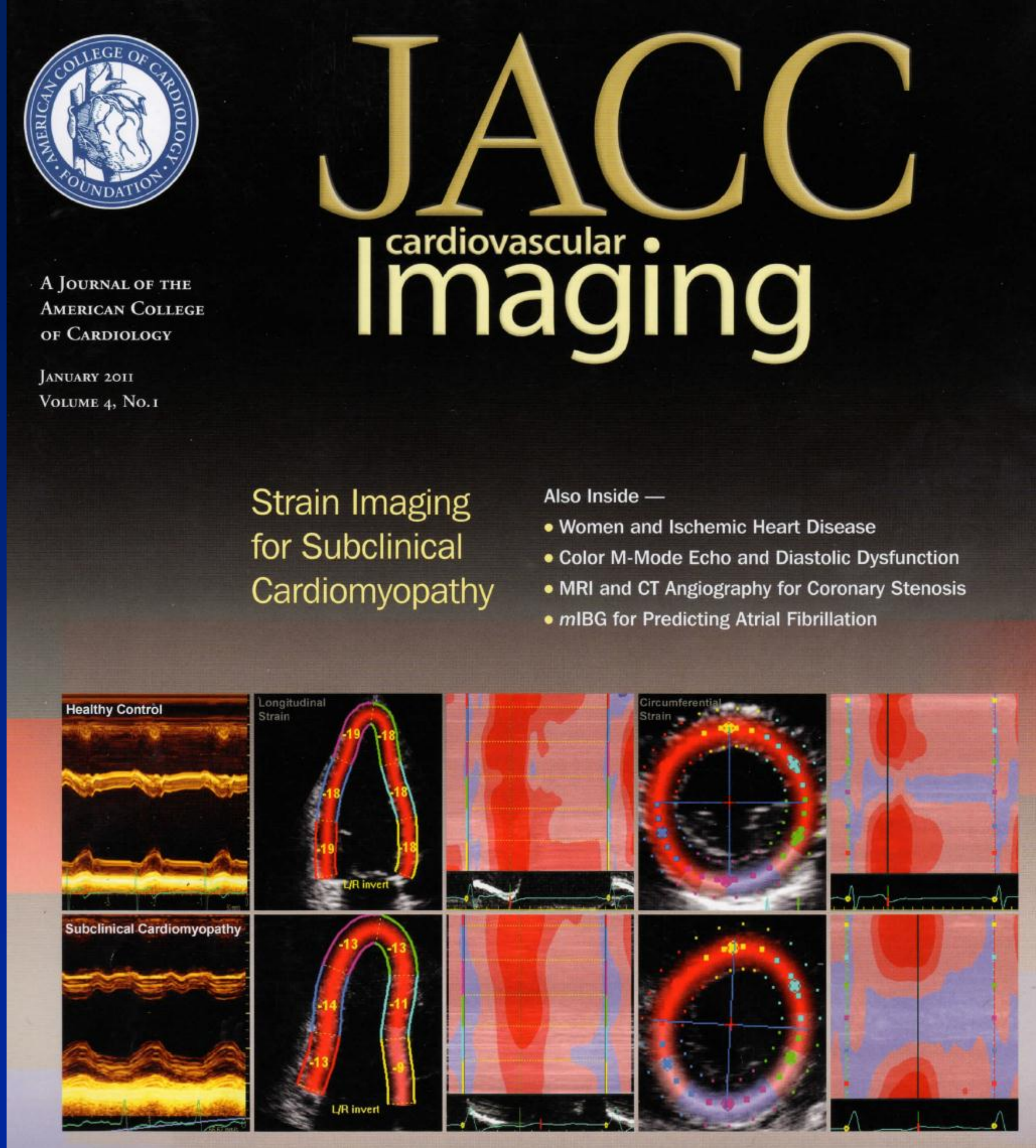
	All Levels	Apical	Mid	Basal	p Value (Levels)
All walls	−18.6 ± 5.1	−20.2 ± 5.6	−18.7 ± 3.8	−17.0 ± 5.2	<0.0001
Anterior	−19.5 ± 4.2	−19.4 ± 5.4	−18.8 ± 3.4	−20.1 ± 4.0	0.001
Anteroseptal	−18.8 ± 4.2	−18.8 ± 5.9	−19.4 ± 3.2	−18.3 ± 3.5	0.001
Inferior	−20.0 ± 4.5*	−22.5 ± 4.5	−20.4 ± 3.5	−17.1 ± 3.9	<0.0001
Lateral	−18.3 ± 4.7	−19.2 ± 5.4	−18.1 ± 3.5	−17.8 ± 5.0	0.06
Posterior	−16.3 ± 6.3†	−17.7 ± 6.0	−16.8 ± 5.0	−14.6 ± 7.4	<0.0001
Septal	−18.3 ± 5.3	−22.3 ± 4.8	−18.7 ± 3.0	−13.7 ± 4.0	<0.0001
p (walls)	<0.0001	<0.0001	<0.0001	<0.0001	

*Inferior was significantly different from all other walls ($p < 0.001$ except anterior $p = 0.02$), in the comparison of walls at all levels. †Posterior was significantly different from all other walls ($p < 0.0001$). In the comparison of levels in all walls, each level was significantly different ($p < 0.0001$).

LV = left ventricular; TQ = tracking quality.

JACC cardiovascular Imaging

Why is Strain Clinically Important and When to Consider its use?



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1. General population

Original Articles

Prediction of All-Cause Mortality From Global Longitudinal Speckle Strain

Comparison With Ejection Fraction and Wall Motion Scoring

Tony Stanton, MBChB, PhD; Rodel Leano, BS; Thomas H. Marwick, MBBS, PhD

Objectives

- *Compare GLS with ejection fraction and WMSI for the prediction of mortality*

Staton et al. Circ CV Imaging 2009;2:356-64

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Methods

- *546 consecutive patients (known or suspected LV impairment), 91 died at 5.2 +/-1.5 years*
- *Simpsons biplane EF and WMSI by 2 experienced readers*
- *Global longitudinal strain (GLS) was calculated in 3 views using 2D Speckle tracking (18 segments)*
- *The incremental value of EF/WMSI and GLS to significant clinical variables was assessed using a nested Cox model*

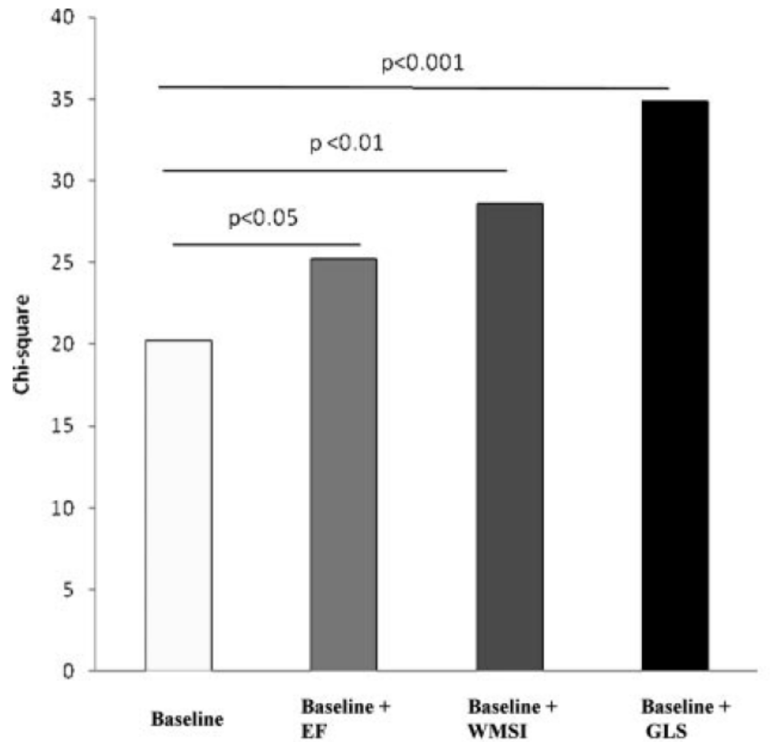
Staton et al. Circ CV Imaging 2009;2:356-64

Results

- *Mean EF = 58 +/- 12% (16-81%)*
- *WMSI = 1.3 +/-0.4*
- *GLS = -16.6 +/-4.3 %*

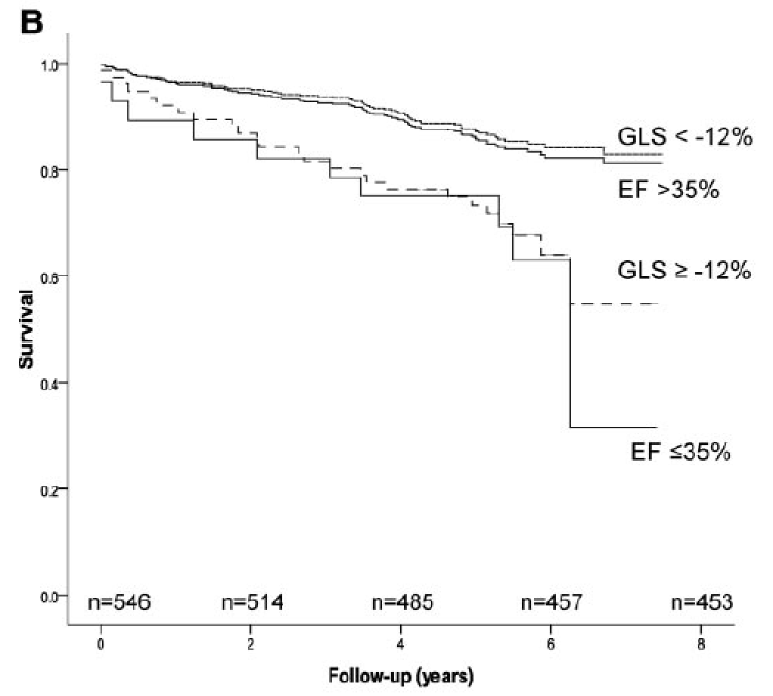
Circulation Cardiovascular Imaging
Journal of the American Heart Association
American Heart Association Learn and Live

Staton et al. Circ CV Imaging 2009;2:356-64



	HR	p	HR	p	HR	p	HR	p
Age	1.46	<0.001						
Diabetes	1.66	0.02						
Hypertension	1.39	0.14						
EF			1.23	<0.05				
WMSI					1.28	<0.01		
GLS							1.45	<0.001

EF = ejection fraction, WMSI = wall motion score index, GLS = global longitudinal strain



Staton et al. Circ CV Imaging 2009;2:356-64

Conclusions

- GLS is a superior predictor of outcome to either EF or WMSI.
- It may become the optimal method of assessment of global LV function
- A GLS $\geq$ -12% was found to be equivalent to an EF $\leq$ 35% for the prediction of prognosis
- Use of this threshold could possibly improve access to potentially lifesaving treatments such as implantable defibrillators.

Circulation Cardiovascular Imaging
JOURNAL OF THE AMERICAN HEART ASSOCIATION
American Heart Association *Learn and Live*

Staton et al. Circ CV Imaging 2009;2:356-64

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2. Heart failure

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Global 2-Dimensional Strain as a New Prognosticator in Patients With Heart Failure

Goo-Yeong Cho, MD, PHD,* Thomas H. Marwick, MD, PHD,† Hyun-Sook Kim, MD, PHD,‡ Min-Kyu Kim, MD,‡ Kyung-Soon Hong, MD, PHD,‡ Dong-Jin Oh, MD, PHD‡

Seoul, South Korea; and Brisbane, Queensland, Australia

Objectives We sought to evaluate whether global 2-dimensional (2D) strain offers additional benefit over left ventricular ejection fraction (LVEF) to predict clinical events in heart failure.

Background Although 2D strain based on speckle tracking has been proposed as a simple and reproducible tool to detect systolic dysfunction, the relationship of 2D strain and prognosis has not been studied.

Methods Two hundred one patients (age 63 ± 11 years, 34% female, LVEF 34 ± 13%) hospitalized for acute heart failure underwent clinical evaluation and conventional and tissue Doppler echocardiography. Using dedicated software, we measured the global longitudinal strain (GLS) in apical 4- and 2-chamber views and the global circumferential strain (GCS) in a parasternal short-axis view. Cardiac events were defined as readmission for heart failure or cardiac death.

Results There were 23.4% clinical events during 39 ± 17 months of follow-up. In univariate analysis, age, left atrial volume, left ventricular volume, LVEF, ratio of early transmitral flow to early diastolic annular velocity (E/e′), and both GLS and GCS were predictive of cardiac events. In multivariate Cox models, age (hazard ratio [HR]: 1.06, 95% confidence interval [CI]: 1.01 to 1.10, $p = 0.017$) and GCS (HR: 1.15, 95% CI: 1.04 to 1.28; $p = 0.006$) were independently associated with cardiac events. By Cox proportional hazards model, the addition of GCS markedly improved the prognostic utility of a model containing ejection fraction, E/e′, and GLS.

Conclusions GCS is a powerful predictor of cardiac events and appears to be a better parameter than ejection fraction in patients with acute heart failure. (J Am Coll Cardiol 2009;54:618–24)

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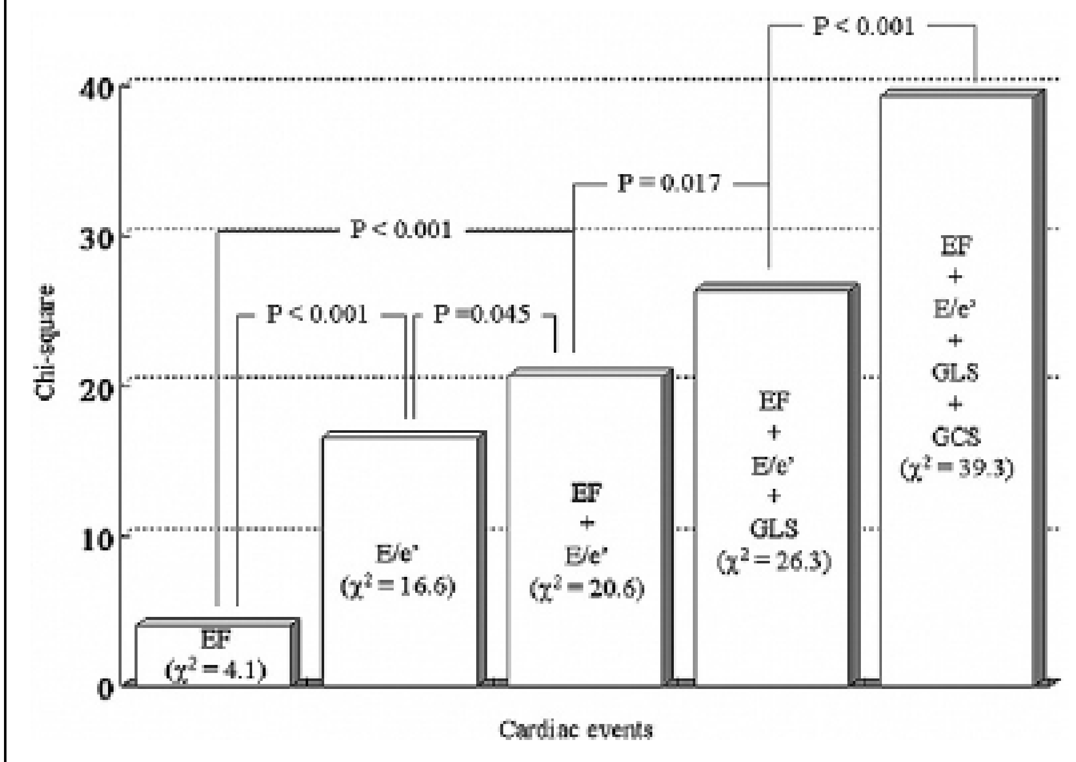

Figure 3 **Prognostic Value of Echocardiographic Parameters**

Incremental prognostic value of the risk factors (ratio of early transmitral flow to early diastolic annular velocity [E/e′], left ventricular ejection fraction, GLS, and GCS) by Cox proportional hazards model presented as a global chi-square value. The addition of GCS resulted in significant incremental improvement in the predictive value on the E/e′, ejection fraction (EF), and GLS. Abbreviations as in Figure 1.

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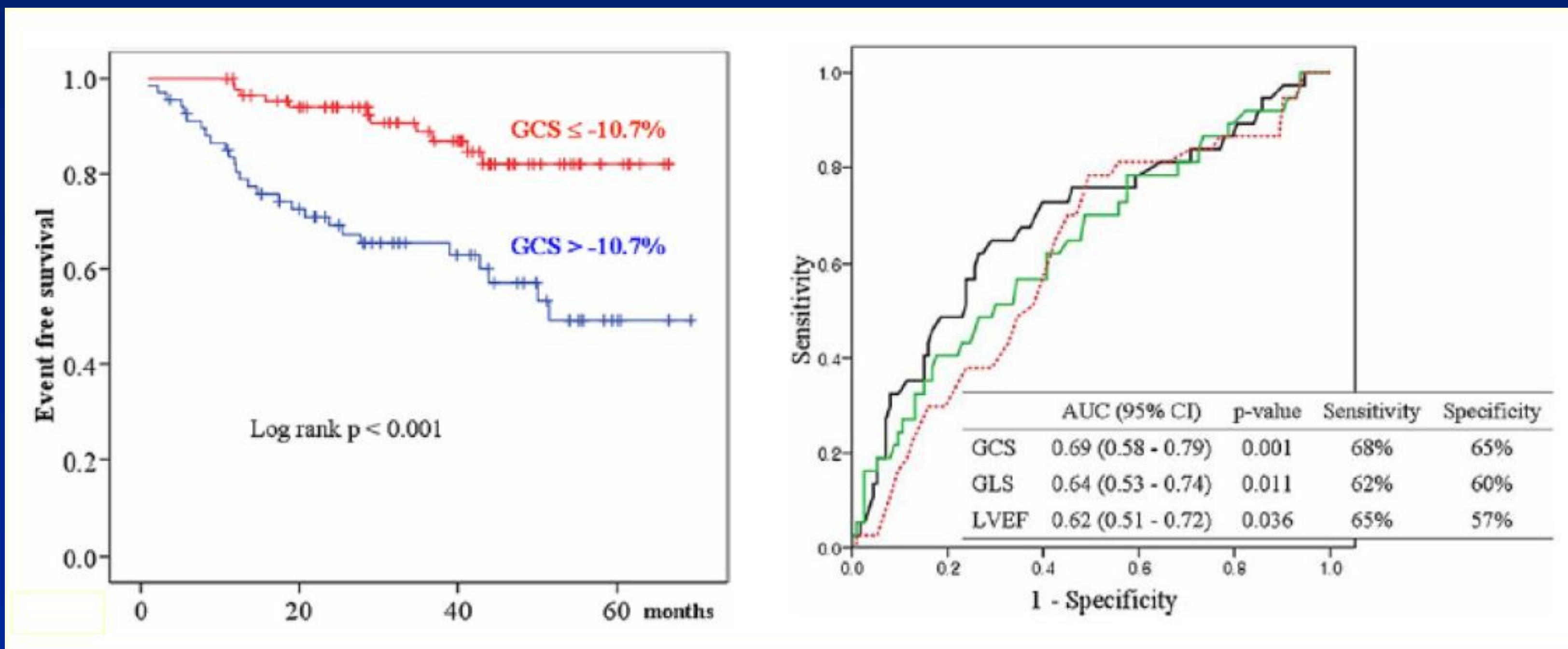
Prognosis Prediction in Patients with Acute Heart Failure



Cho GY, JACC 2009;54:618

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3. Evaluation of Myocardial Ischemia

Strain in Myocardial Ischemia

Table 2 Studies assessing strain and twist in CAD

Study	Subjects (n)	Purpose	Principal observations
Resting echocardiography			
Choi et al (2009)[37]	CAD (66), controls (30)	Assessment of LS in CAD	LS correlated with the degree of coronary artery stenosis
Liang et al (2006)[36]	CAD (39), controls (15)	Assessment of LS in CAD	Decreased LS in ischemic segments
Stress echocardiography			
Bansal et al (2008)[52]	MI (44), no MI (41)	LV rotation with DSE	LV rotation reduced in infarcted segments but not in ischemic regions
Chan et al (2006)[43]	MI (80)	Transmurality of MI by DSE and CE-MRI	Transmural infarcts showed lower CS, but similar LS and RS as subendocardial infarcts
Hanekom et al (2007)[50]	CAD (150)	STE and DTI compared during DSE	Correlation better in anterior than posterior circulation
Ishii et al (2009)[51]	Stable angina (162)	Assessment of LS during stress test	LS detected CAD with 97% sensitivity and 93% specificity
MI/chronic CAD/ICM			
Becker et al (2006)[48]	MI (47)	Transmurality of MI, STE vs CE-MRI	RS had 70% sensitivity and 71% specificity in identifying non-transmural MI
Bertini et al (2009)[47]	MI (50), ICM (49), non-ICM (38), controls (28)	Evaluation of LV twist	Reduced twist in all patient populations correlated with LV systolic function
Chen et al (2007)[144]	MI (20), controls (15)	LV strain in MI	Reduced LS in comparison with controls
Gjesdal et al (2007)[42]	MI (38), controls (15)	Comparison with CE-MRI	LS had 83% sensitivity and 93% specificity in identifying MI
Delgado et al (2008)[44]	STEMI (99), ICM (123), controls (20)	LS compared with LV EF	LS correlated with LV EF
Jurcut et al (2008)[38]	MI (32), controls (20)	Comparison with CE-MRI	LS had 91% sensitivity and 90% specificity in identifying MI
Park et al (2008)[40]	No remodeling (28), remodeling (22)	Prediction of remodeling following revascularization	LS independently predicted LV remodeling
Roes et al (2009)[16]	CAD (90)	Comparison with CE-MRI	LS discriminated transmural from non-transmural scar
Takeuchi et al (2007)[45]	MI (30), controls (15)	LV twist in MI	CS and twisting velocity was reduced in patients with low EF
Revascularization/medical therapy			
Blondheim et al (2007)[55]	ICM (21)	Effects of medical therapy	Improvement in segmental LS
Becker et al (2008)[57]	MI (53)	Comparison with CE-MRI	RS predicted functional recovery (sensitivity, 70%; specificity, 85%)
Bertini et al (2009)[39]	MI (157)	Comparison with door-to-balloon times	Reduced LS correlated with cTnT and door-to-balloon times
Park et al (2008)[40]	No remodeling (28), remodeling (22)	LS in AMI following revascularization	LS independently predicted LV remodeling
Han et al (2008)[56]	MI (35), controls (32)	Twist in MI following revascularization	Improvement in twist following revascularization
Hoffmann et al (2009)[58]	MI (59)	Effect of revascularization, STE compared with CE-MRI	Peak systolic RS predicted functional recovery
Ishii et al (2009)[53]	CAD (30)	Effects of balloon occlusion	Reduction LS in affected and at-risk segments during occlusion
Winter et al (2007)[54]	CAD (8)	Effects of balloon occlusion	Decreased RS and CS

AMI, Acute myocardial infarction; *CAD*, coronary artery disease; *CE-MRI*, cardiac MRI; *CS*, circumferential strain; *cTnT*, cardiac troponin T; *DSE*, dobutamine stress echocardiography; *EF*, ejection fraction; *ICM*, ischemic cardiomyopathy; *LS*, longitudinal strain; *MI*, myocardial infarction; *RS*, radial strain; STEMI, ST-elevation myocardial infarction.

Geyer H et al. JASE 2010;23:351-69

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Strain in Myocardial Disease

- *Importance of Longitudinal Strain*
  - Longitudinal fibers are predominant in the subendocardial region
  - Most vulnerable component of LV mechanics and therefore most sensitive to the presence of myocardial disease.

Table 1 Classification of cardiac mechanics in heart failure

Functional impairment	Longitudinal mechanics	Circumferential mechanics	Radial mechanics	Torsional mechanics	Global EF	Diastolic filling pressures	Clinical syndrome
Predominant subendocardial dysfunction	Marked impairment	Preserved	Preserved/minimal impairment	Preserved	Preserved/minimal impairment	Elevated	Diastolic HF/HFNEF
Predominant subepicardial dysfunction	Preserved/minimal impairment	Marked impairment	Minimal impairment	Marked impairment	Preserved/minimal impairment	Elevated	Diastolic HF/HFNEF
Transmural dysfunction	Marked impairment	Marked impairment	Marked impairment	Marked impairment	Marked impairment	Elevated	Systolic HF

EF, Ejection fraction; *HF*, heart failure; *HFNEF*, heart failure and normal ejection fraction.

Geyer H et al. JASE 2010;23:351-69

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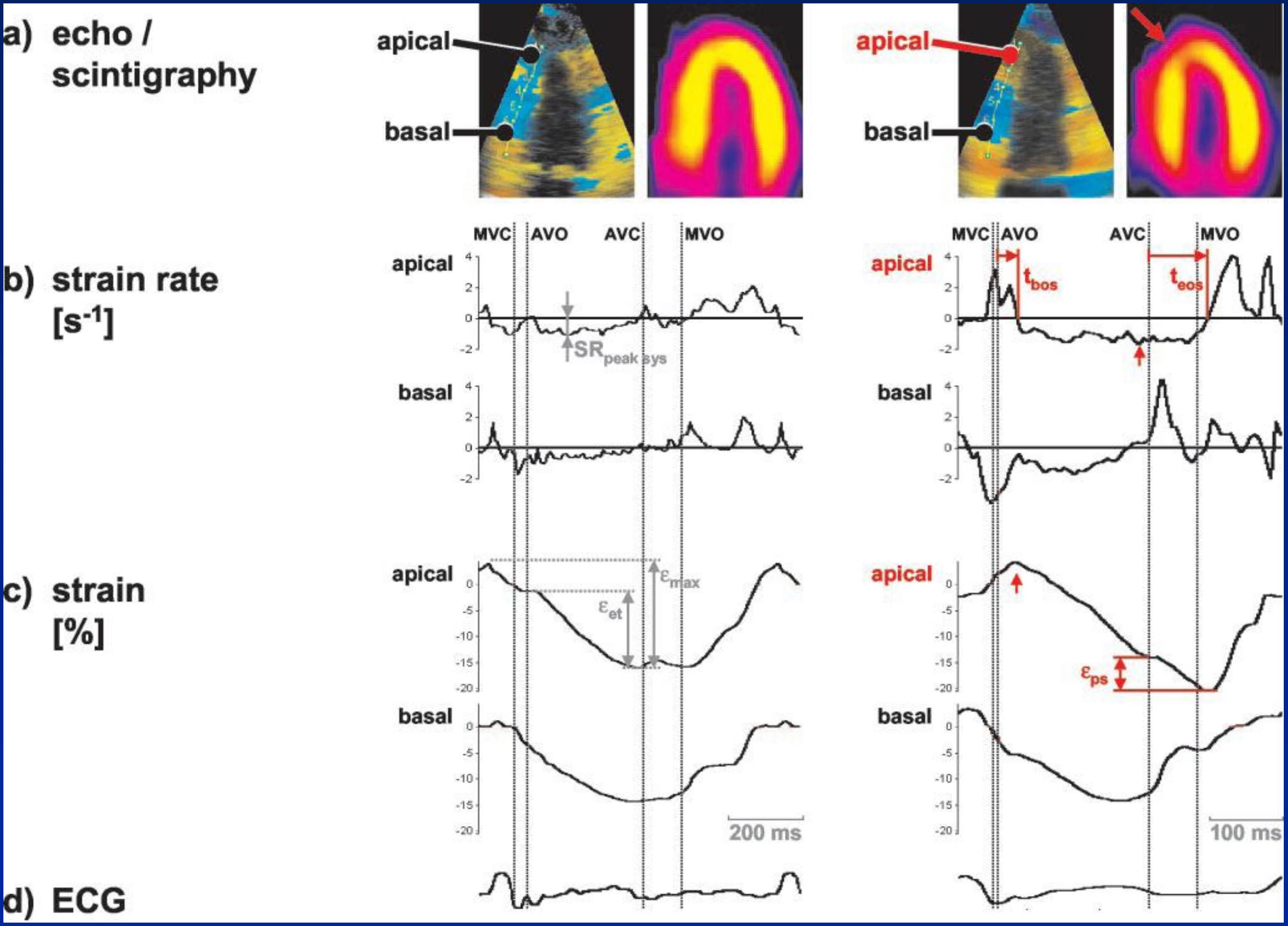
Strain Imaging During DSE



Voigt et al. Circulation 2003;107:2120-26

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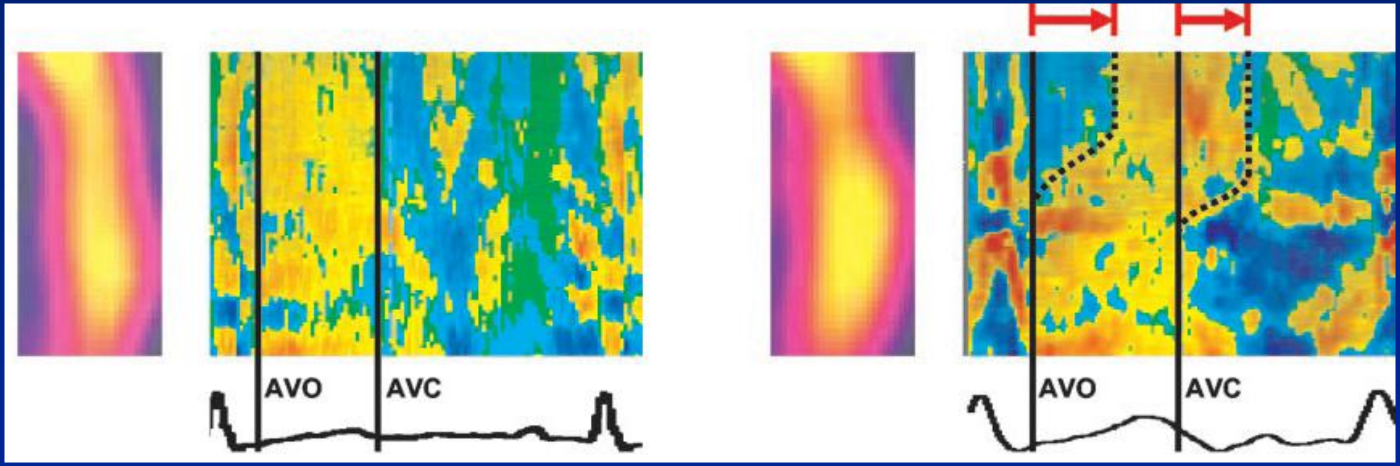
Strain Imaging During DSE
Post-Systolic Shortening in Ischemia

Normal *Ischemic*



SRI M-mode / Curved M-mode

Voigt et al. Circulation 2003;107:2120-26

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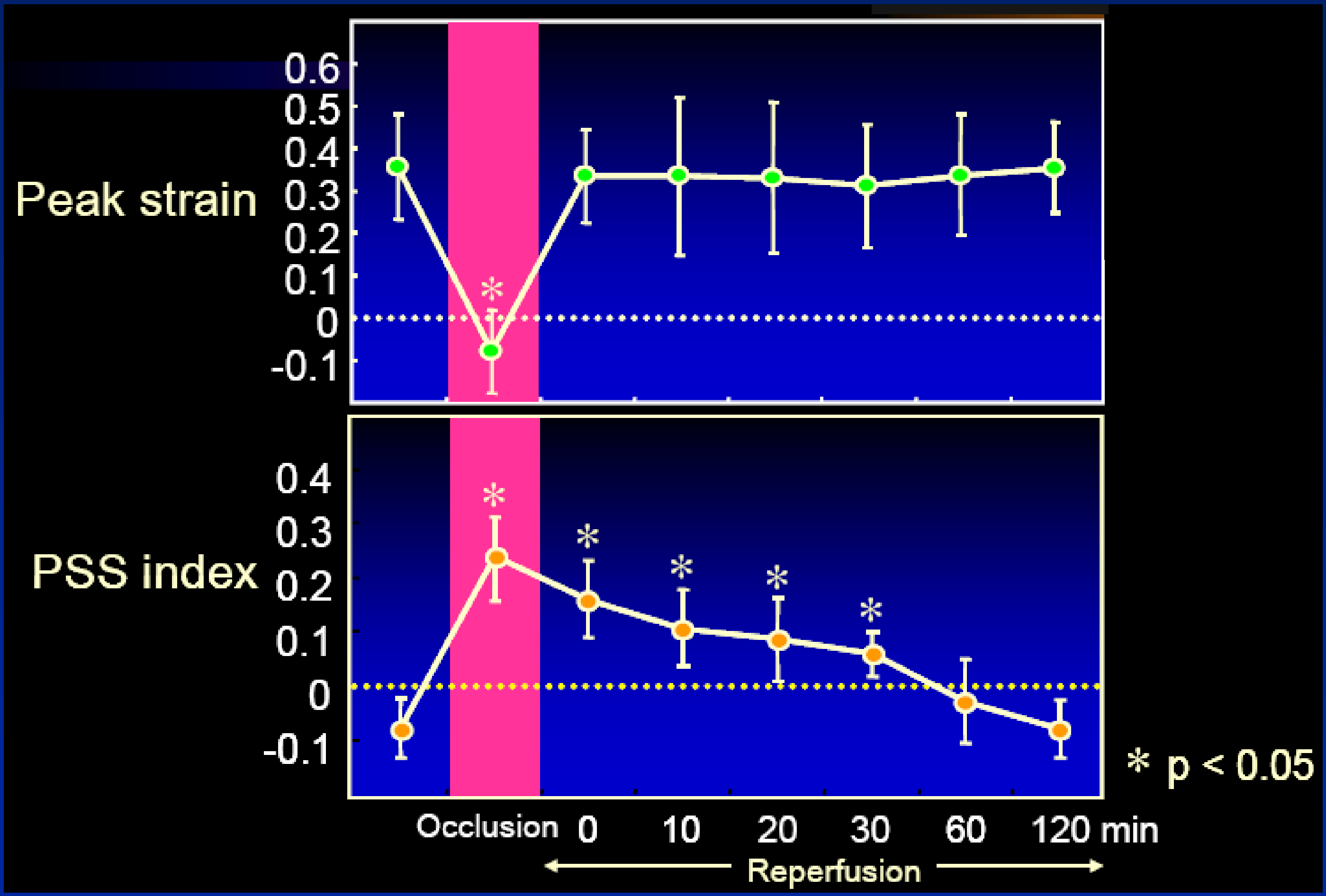
PSS Lasts Longer Than Strain Decrease



Courtesy of Dr Ishii and Nakatani

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4. Early detection of cardiotoxicity from chemotherapy

Use of myocardial deformation imaging to detect preclinical myocardial dysfunction before conventional measures in patients undergoing breast cancer treatment with trastuzumab

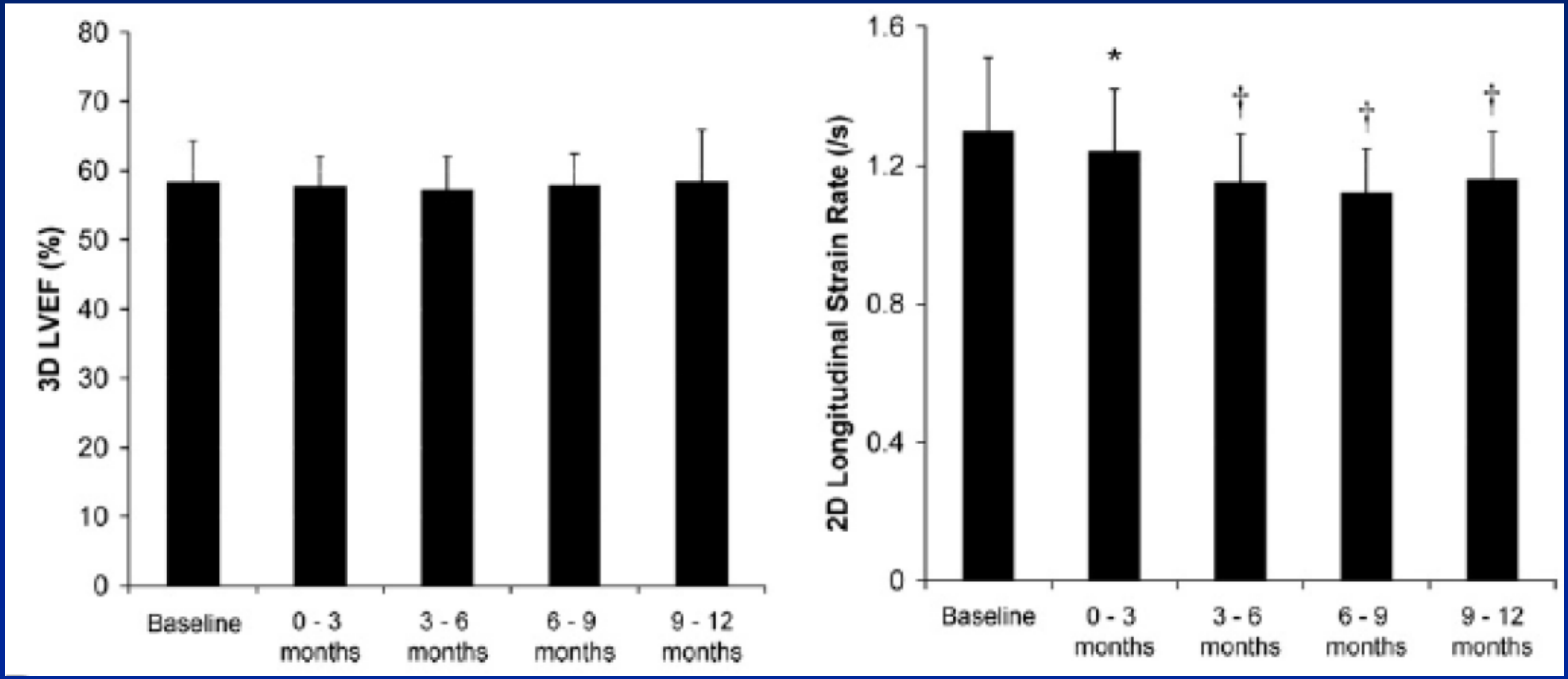
James L. Hare, MBBS,[a] Joseph K. Brown, BSc,[a] Rodel Leano, BSc,[a] Carly Jenkins, MSc,[a] Natasha Woodward, MBBS,[b] and Thomas H. Marwick, MBBS, PhD[a] *Brisbane, Australia*

Background Trastuzumab prolongs survival in patients with human epidermal growth factor receptor type 2–positive breast cancer. Sequential left ventricular (LV) ejection fraction (EF) assessment has been mandated to detect myocardial dysfunction because of the risk of heart failure with this treatment. Myocardial deformation imaging is a sensitive means of detecting LV dysfunction, but this technique has not been evaluated in patients treated with trastuzumab. The aim of this study was to investigate whether changes in tissue deformation, assessed by myocardial strain and strain rate (SR), are able to identify LV dysfunction earlier than conventional echocardiographic measures in patients treated with trastuzumab.

Methods Sequential echocardiograms (n = 152) were performed in 35 female patients (51 ± 8 years) undergoing trastuzumab therapy for human epidermal growth factor receptor type 2–positive breast cancer. Left ventricular EF was measured by 2- and 3-dimensional (2D and 3D) echocardiography, and myocardial deformation was assessed using tissue Doppler imaging and 2D-based (speckle-tracking) strain and SR. Change over time was compared every 3 months between baseline and 12 months.

Conclusions Myocardial deformation identifies preclinical myocardial dysfunction earlier than conventional measures in women undergoing treatment with trastuzumab for breast cancer. (Am Heart J 2009;158:294-301.)

3D LVEF vs. Longitudinal Strain Rate



Hare JL et al. Am Heart J. 2009;158(2):294-301

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Early Detection and Prediction of Cardiotoxicity in Chemotherapy-Treated Patients

Heloisa Sawaya, MD, PhD[a]; Igal A. Sebag MD[d]; Juan Carlos Plana, MD[f]; James L. Januzzi, MD[a]; Bonnie Ky, MD[g]; Victor Cohen, MD[g]; Sucheta Gosavi, MD[a]; Joseph R. Carver, MD[e]; Susan E. Wiegers, MD[g]; Randolph P. Martin, MD[h]; Michael H. Picard, MD[a]; Robert E. Gerszten, MD[a]; Elkan F. Halpern, PhD[c]; Jonathan Passeri, MD[a]; Irene Kuter, MD[b]; Marielle Scherrer-Crosbie, MD, PhD[a] *

- ***Objectives:*** ***To evaluate if more sensitive echocardiographic measurements and biomarkers could predict later cardiac dysfunction in chemo-treated patients***

Slides courtesy of Dr. Plana.
AJC, *in press*.

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Univariate Analysis of Predictors of Cardiotoxicity

Variable	Cardiotoxicity No (N=34)	Cardiotoxicity Yes (N=9)	P value (prediction of Cardiotoxicity)	OR	CI
Change in left ventricular ejection fraction at 3 months (%)	1.2 ± 9	5.6 ± 8	0.19	5.5	0.45 - 100
Change in longitudinal strain at 3 months (%)	3 ± 10	15 ± 8	0.01	500	6.7- $0.11x10^6$
Change in radial strain at 3 months (%)	2 ± 23	22 ± 22	0.02	250	4 - $0.4x10^5$
Change in N-terminal pro B type natriuretic peptide at 3 months (%)	46 ± 240	56 ± 190	0.91	1	0.65 - 1.4
Elevation high sensitivity cardiac Troponin I at 3 months	6 (18%)	6 (67%)	0.006	9	1.8 - 50

Slides courtesy of Dr. Plana.
AJC, *in press*.

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Univariate Analysis of Cardiotoxicity - Diastolic Indices

Variable	Cardiotoxicity No (N=34)	Cardiotoxicity Yes (N=9)	P Value Prediction of Cardiotoxicity)	OR	CI
ΔLAD at 3 months, mm	0.01 ± 0.12	0.05 ± 0.11	0.19	0.01	8.68×10^{-6} – 6.90
ΔE, at 3 months, %	5 ± 20	1 ± 21	0.47	4.57	0.12 – 201.2
ΔE/A at 3 months, %	2 ± 24	10 ± 41	0.28	4.05	0.31 – 61.47
ΔE'at 3 months, %	6 ± 16	7 ± 17	0.80	0.53	0.003 – 7.59
ΔE/E' at 3 months, %	3 ± 25	15 ± 31	0.25	0.17	0.007 – 3.39

Slides courtesy of Dr. Plana.
AJC, *in press*.

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Sensitivity, Specificity, Positive and Negative Value of the Predictors of Cardiotoxicity

	Sensitivity	Specificity	PPV	NPV
10% decrease long strain	7/9 (78%)	27/34 (79%)	7/14 (50%)	27/29 (93%)
Increased cTnl at 3 months	6/9 (67%)	28/34 (82%)	6/12 (50%)	28/31 (90%)
10% decrease long strain and increased cTnl at 3 months	5/9 (55%)	33/34 (97%)	5/6 (83%)	33/37 (89%)
10% decrease long strain or increased cTnl at 3 months	8/9 (89%)	22/34 (65%)	8/20 (40%)	22/23 (97%)

Slides courtesy of Dr. Plana.
AJC, *in press*.

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Other Clinical Applications of Strain

- *Aiding in the identification of Myocardial Dyssynchrony*
- *Regional and Global Function of other cardiac chambers (ie: LA, RV).*
- *Correlation of regional function and myocardial fibrosis in cardiomyopathies. (ie: amyloid, HCM, DCM, etc)*

Geyer H et al. JASE 2010;23:351-69

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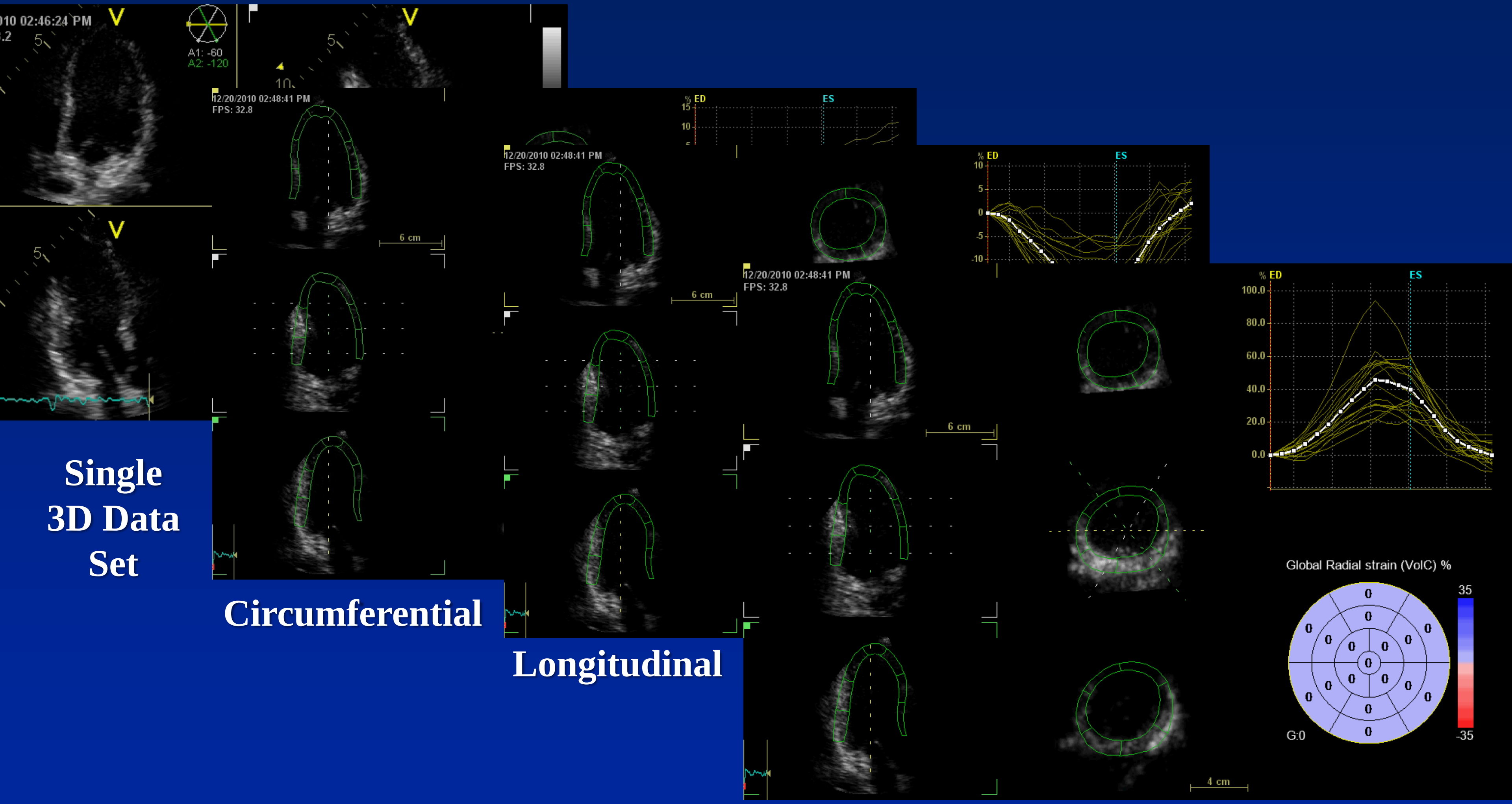
What’s coming up in the near future?

3D Speckle-Tracking



Single
3D Data
Set

Circumferential

Longitudinal

Radial

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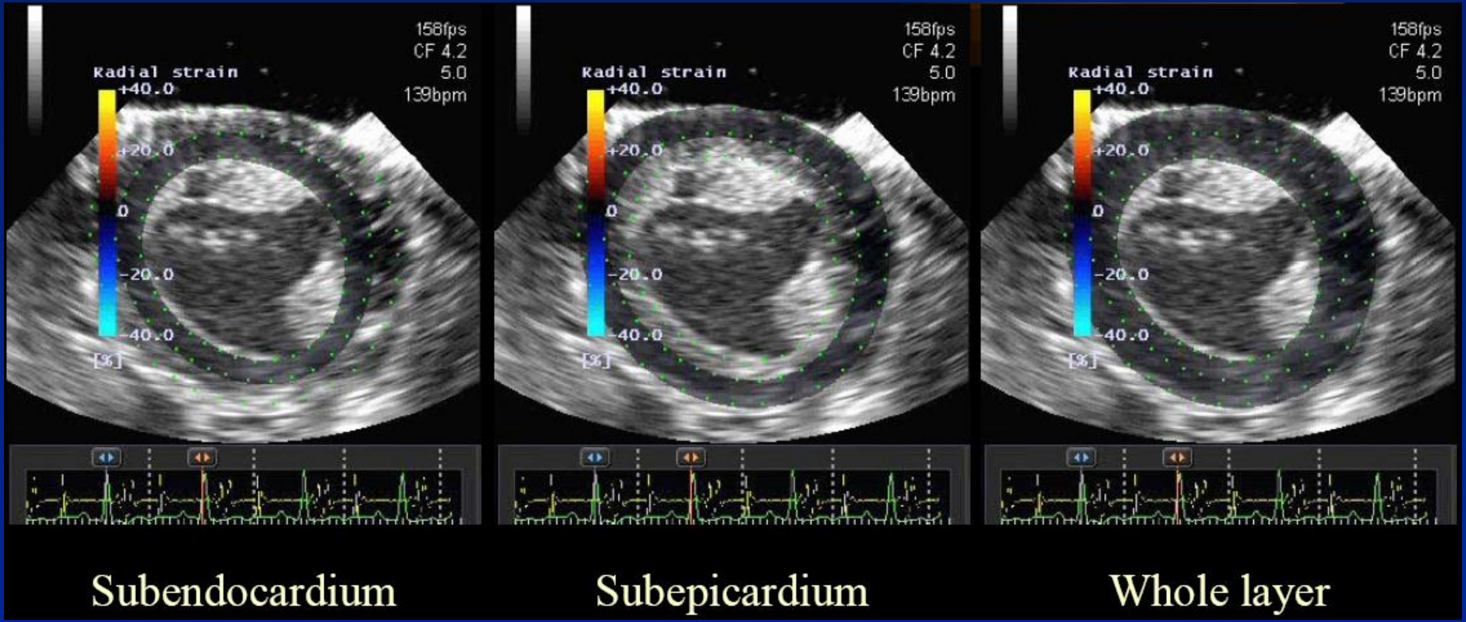
Layer Specific Strain



Strain and Strain Rate

- Free from Translation and Tethering
- Highly dependent on image quality
- It can quantify global and regional myocardial function, adding incremental value to standard measurements.
- *Sensitive marker of functional change, ie: early detection of subclinical abnormality → early intervention*

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